The DUNE experiment: pushing the limits in detector technologies.

HighRR Seminar

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for the DUNE Collaboration
24th February 2021

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

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Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

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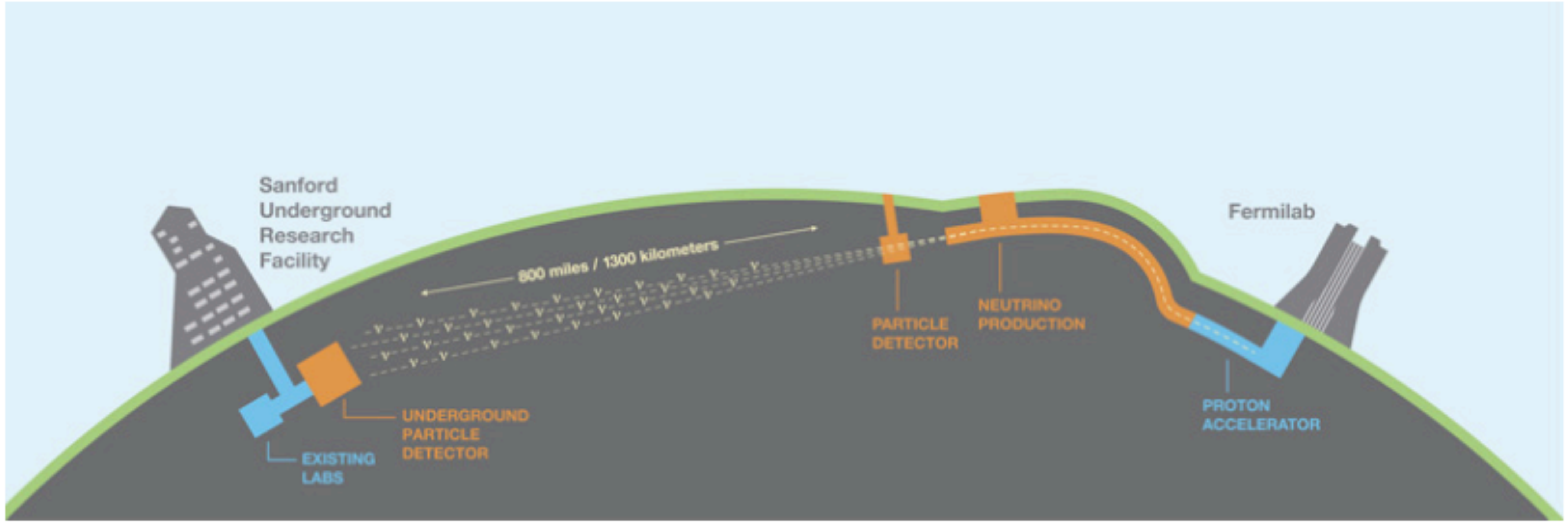

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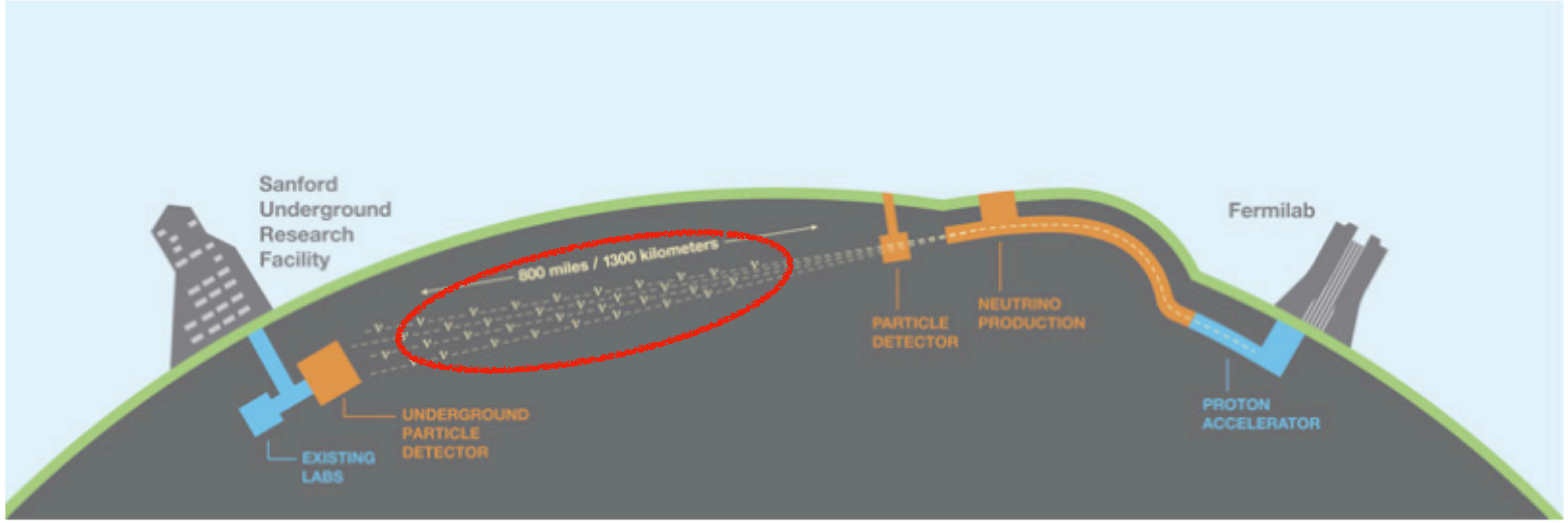
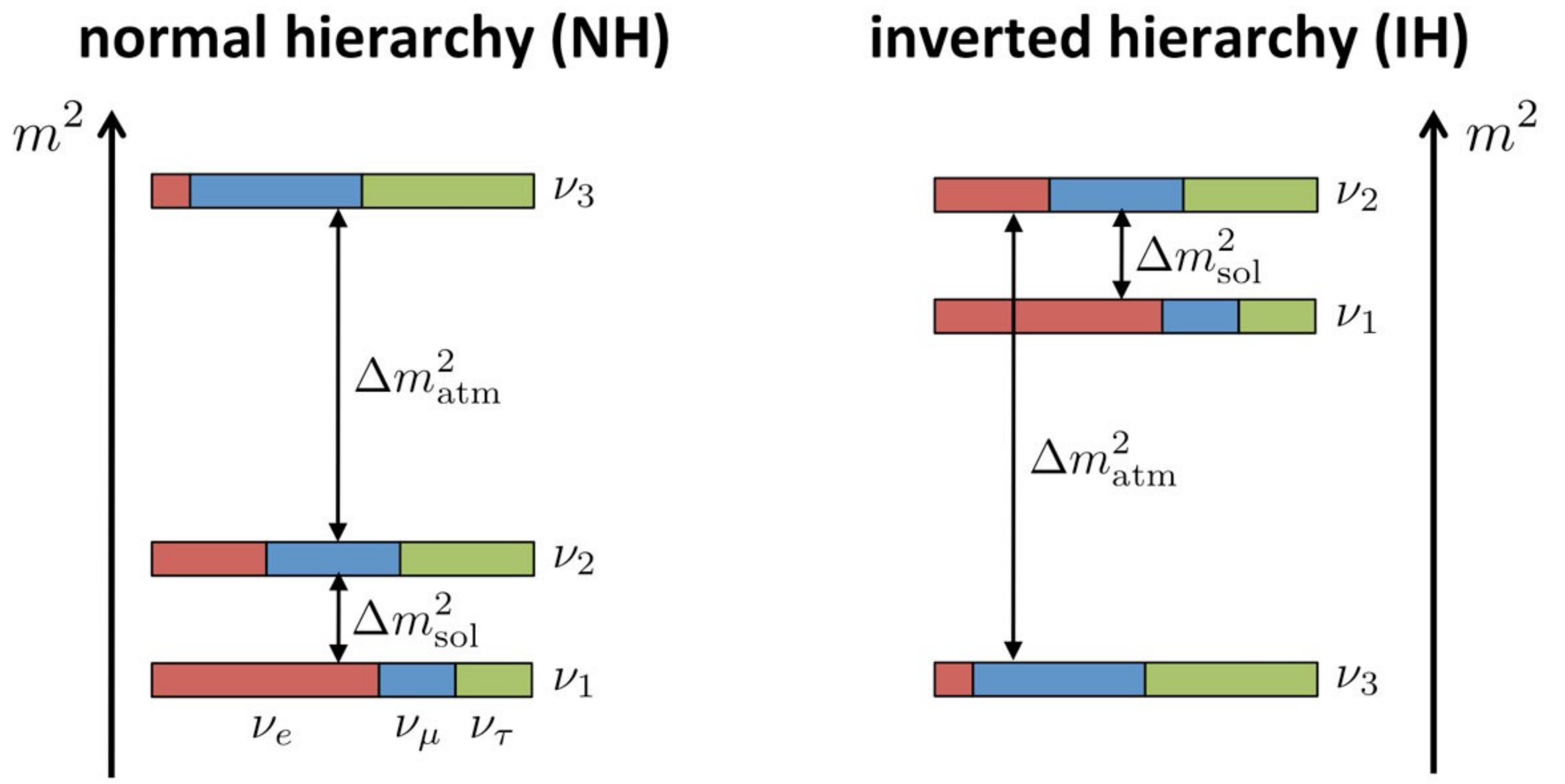


Neutrinos.

The invisible and mysterious particle

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \underbrace{\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}}_{U_{\mathrm{PMNS}}} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

- Neutrino oscillations hypothesised in 1957 ➠ Nobel prize 2015
- Described by the PMNS Matrix (similar to CKM) where the flavour eigenstates are a superposition of mass eigenstates
  - Parametrised by angles (θ_{12}, θ_{23}, θ_{13}) and a phase (δ_{cp})
- The remaining questions
  - **Neutrino mass hierarchy**
    - Are the states v_1 & v_2 lighter or heavier than v_3?
  - **CP violation**
    - $\delta_{cp} \neq 0$ or π? ➠ Neutrino / Anti-neutrino asymmetry
  - **Octant of θ_{23}**
    - sin θ_{23} > / < 0.5 ➠ Maximal mixing?



Parameter	best-fit	3σ
Δm^2_{21} [10^{-5} eV ^{2}]	7.37	6.93 – 7.96
$\Delta m^2_{31(23)}$ [10^{-3} eV ^{2}]	2.56 (2.54)	2.45 – 2.69 (2.42 – 2.66)
$\sin^2\theta_{12}$	0.297	0.250 – 0.354
$\sin^2\theta_{23}$, $\Delta m^2_{31(32)} > 0$	0.425	0.381 – 0.615
$\sin^2\theta_{23}$, $\Delta m^2_{32(31)} < 0$	0.589	0.384 – 0.636
$\sin^2\theta_{13}$, $\Delta m^2_{31(32)} > 0$	0.0215	0.0190 – 0.0240
$\sin^2\theta_{13}$, $\Delta m^2_{32(31)} < 0$	0.0216	0.0190 – 0.0242
δ/π	1.38 (1.31)	2σ: (1.0 - 1.9) (2σ: (0.92-1.88))

Neutrinos.

They can change their flavour??

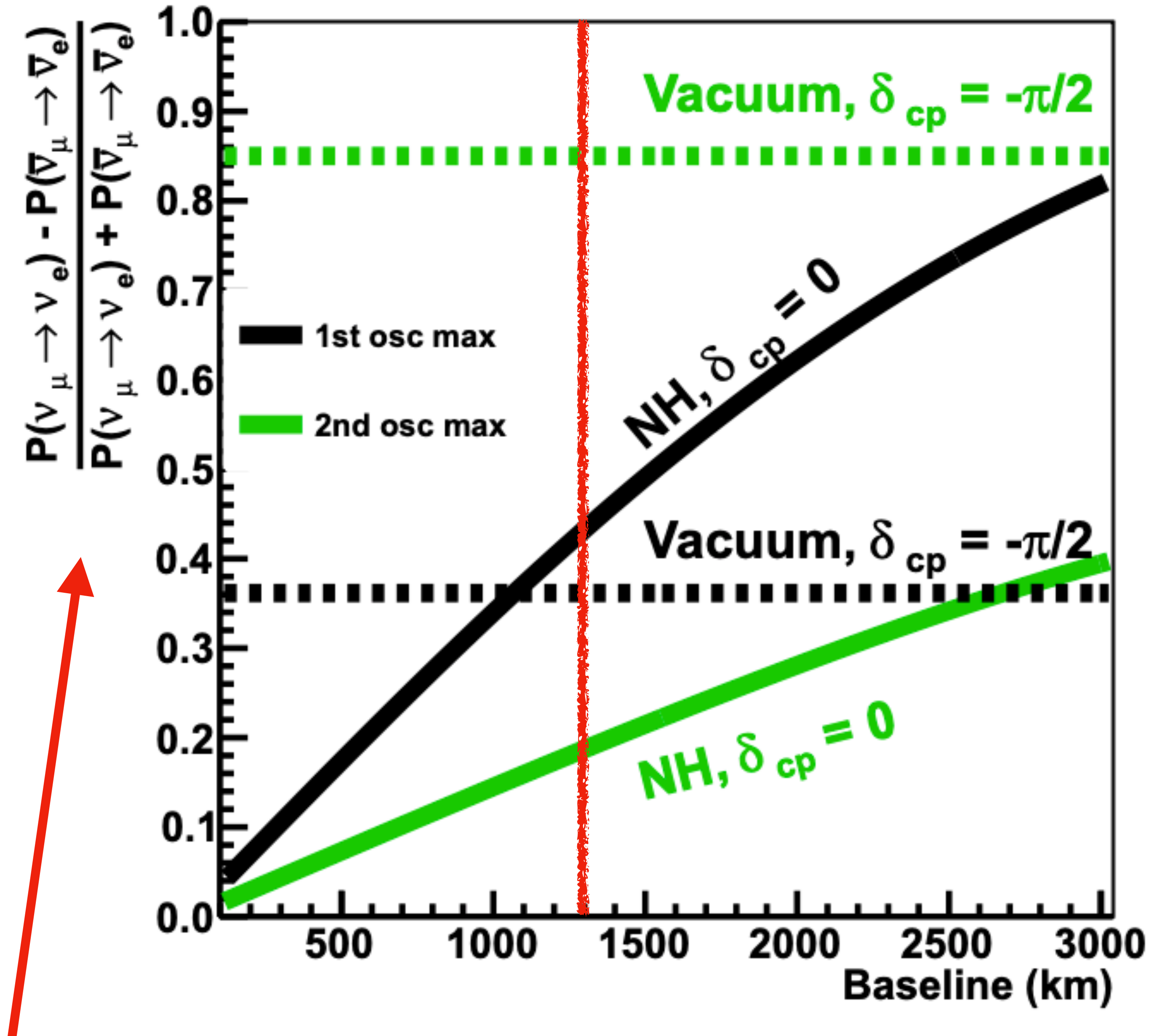
- Oscillation formula (1st order approximation)

$$P(\nu_\mu \to \nu_e) \simeq \sin^2\theta_{23}\sin^2 2\theta_{13}\frac{\sin^2(\Delta_{31}-aL)}{(\Delta_{31}-aL)^2}\Delta_{31}^2 + \sin 2\theta_{23}\sin 2\theta_{13}\sin 2\theta_{12}\frac{\sin(\Delta_{31}-aL)}{(\Delta_{31}-aL)}\Delta_{31}\frac{\sin(aL)}{(aL)}\Delta_{21}\cos(\Delta_{31}+\delta_{CP}) + \cos^2\theta_{23}\sin^2 2\theta_{12}\frac{\sin^2(aL)}{(aL)^2}\Delta_{21}^2,$$

Matter effect!

Neutrino mass effect ($\Delta m^2 E/L$)

CPV effect



arXiv:1311.0212v3

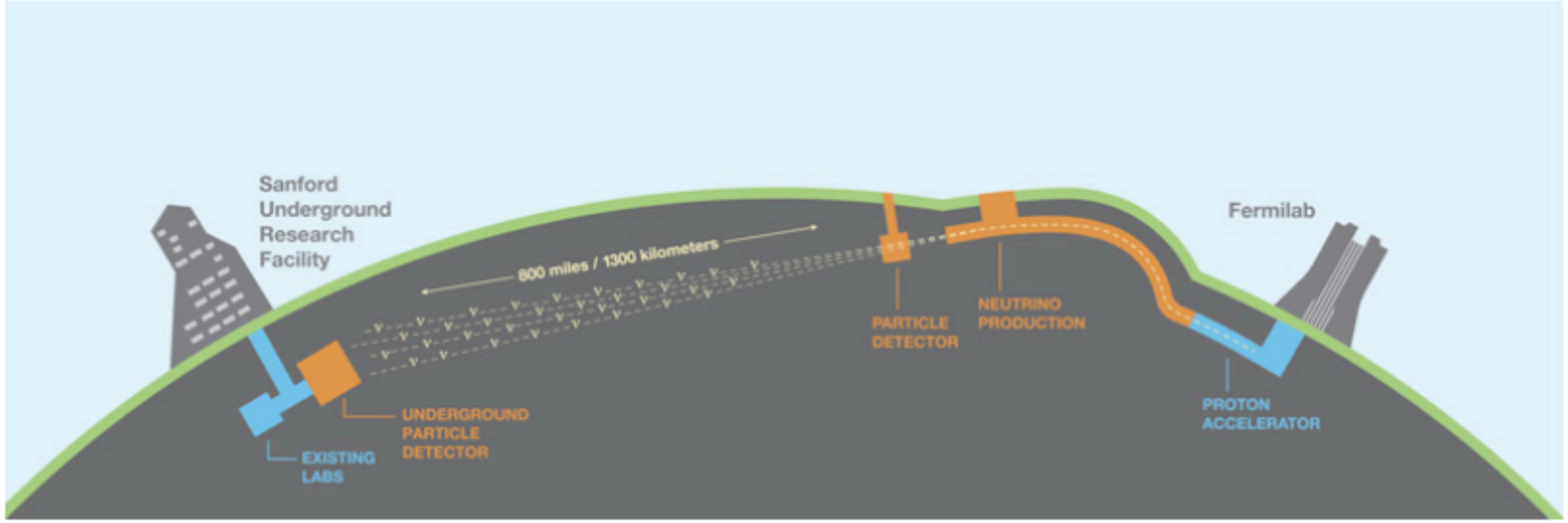
Measure δ_{cp} and mass ordering at the same time

- **Asymmetry**

$$\mathcal{A}_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \sim \frac{\cos\theta_{23}\sin 2\theta_{12}\sin\delta_{CP}}{\sin\theta_{23}\sin\theta_{13}}\left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right) + \text{matter effects}$$

- Matter effect creates asymmetry (even with δ_{cp} = 0 or π) ➠ Baseline with access to second oscillation maximum to have ***better CP sensitivity***

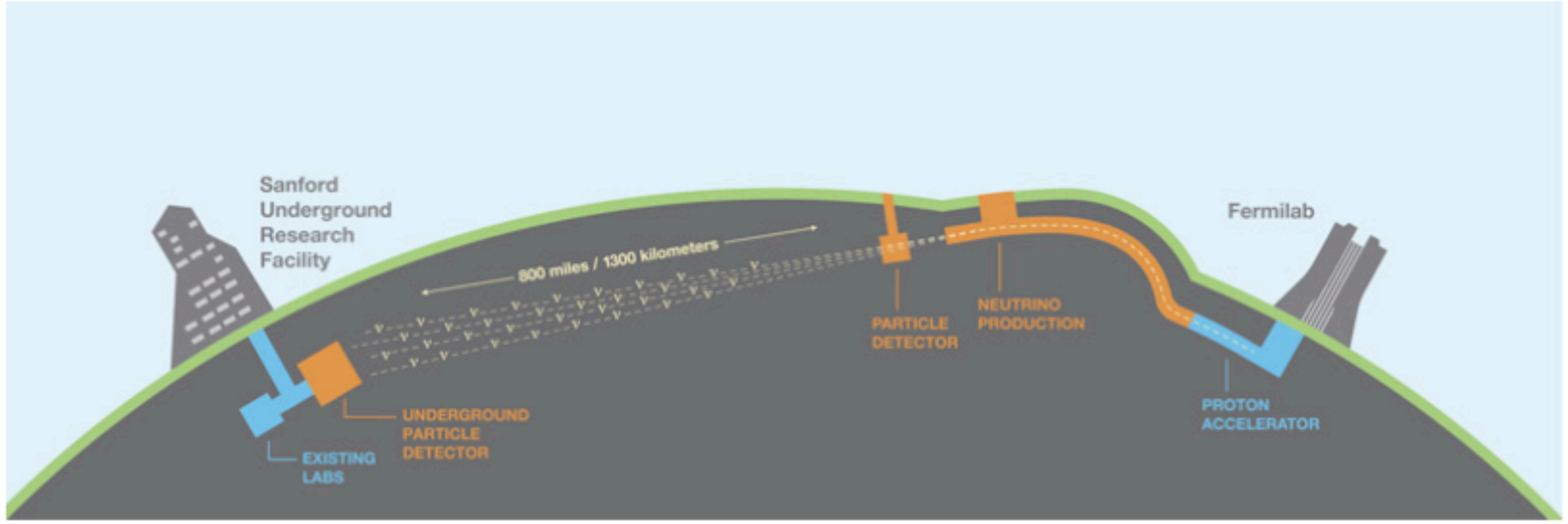
Contents of this talk.

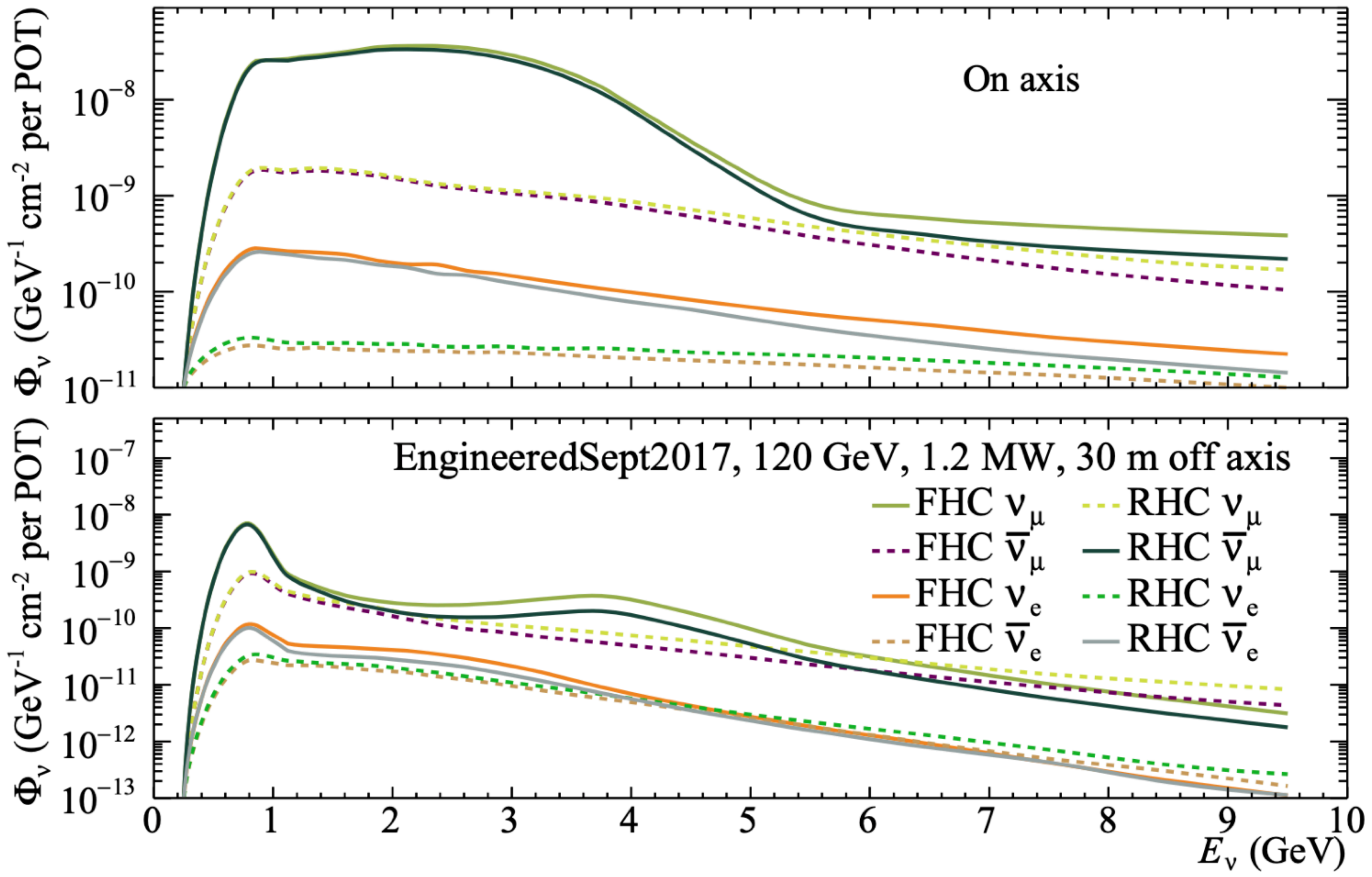


The DUNE Experiment.

Introduction

- The Deep Underground Neutrino Experiment (DUNE) is the next generation **accelerator-based** neutrino experiment
  - Located at Fermilab (Near Detector) and South Dakota (Far Detector)
  - Baseline of **1300 km**
  - World's most intense neutrino beam (**>1 MW**) using *leading-edge* superconducting RF technology (PIP II)
    - 1.2 MW upgrading to 2.4 MW (PIP III)
  - **Wide-band** neutrino beam
- Far Detector complex
  - **40 kT** active target consists of *4 x 10kT* Liquid Argon Time Projection Chambers (LArTPC)
  - **Various technologies** used in the detector designs
- **Highly capable** Near Detector complex
  - Precise characterisation of the neutrino beam (spectrum and flavour) and precise cross-section measurements





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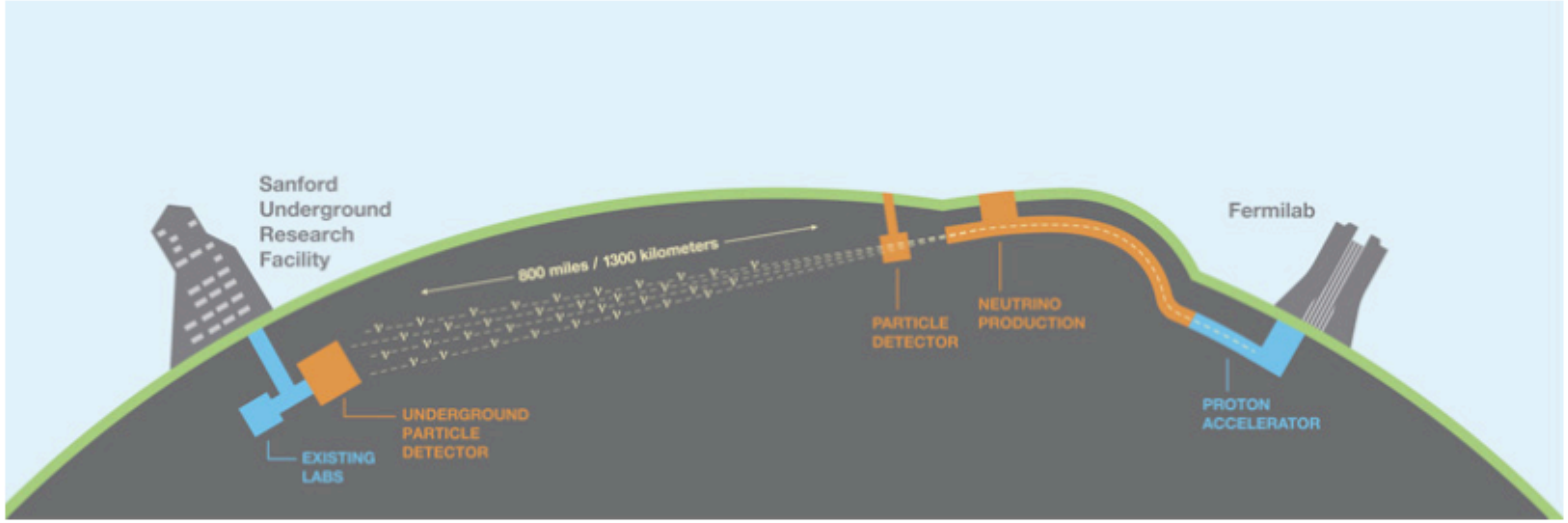
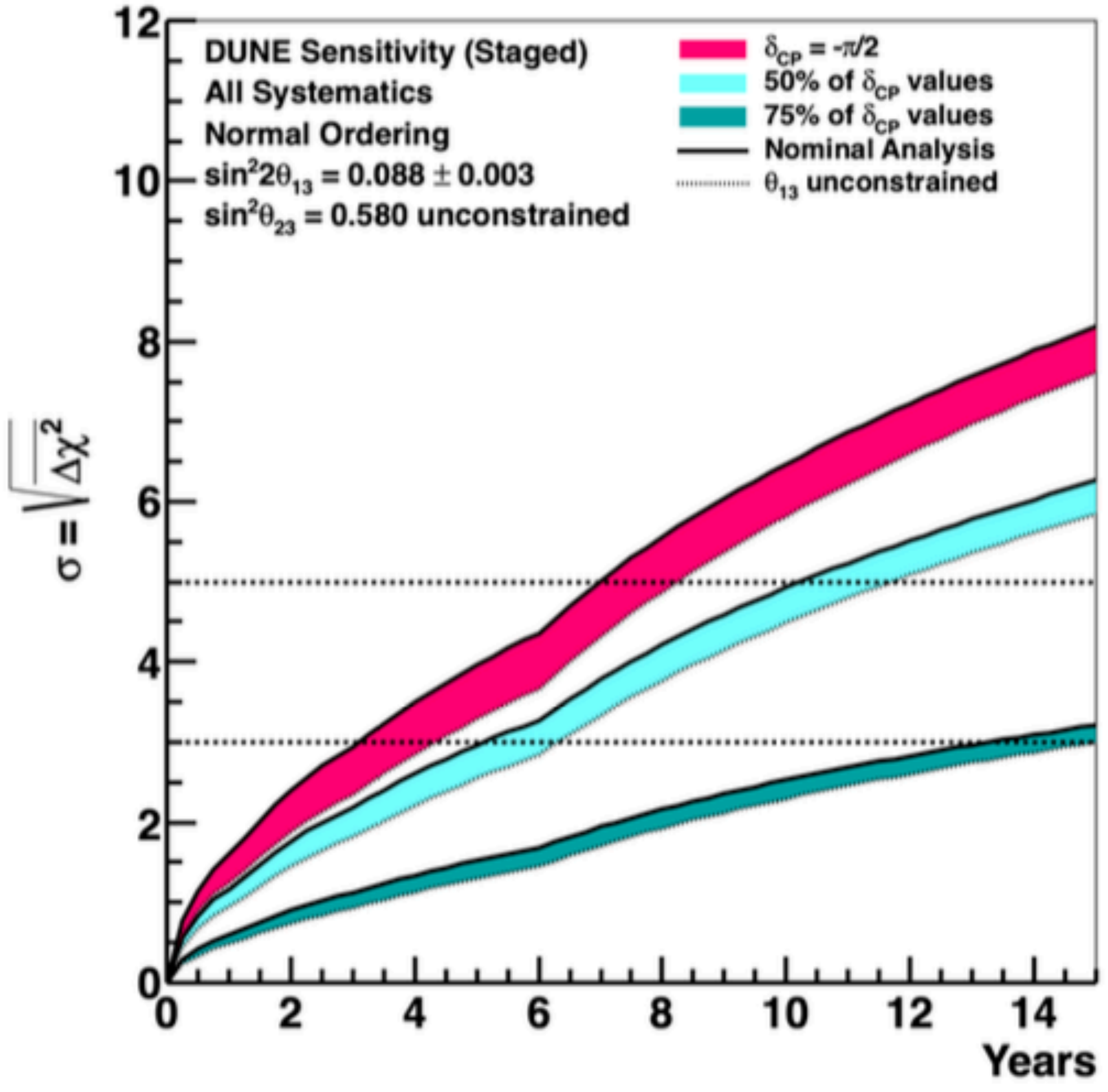
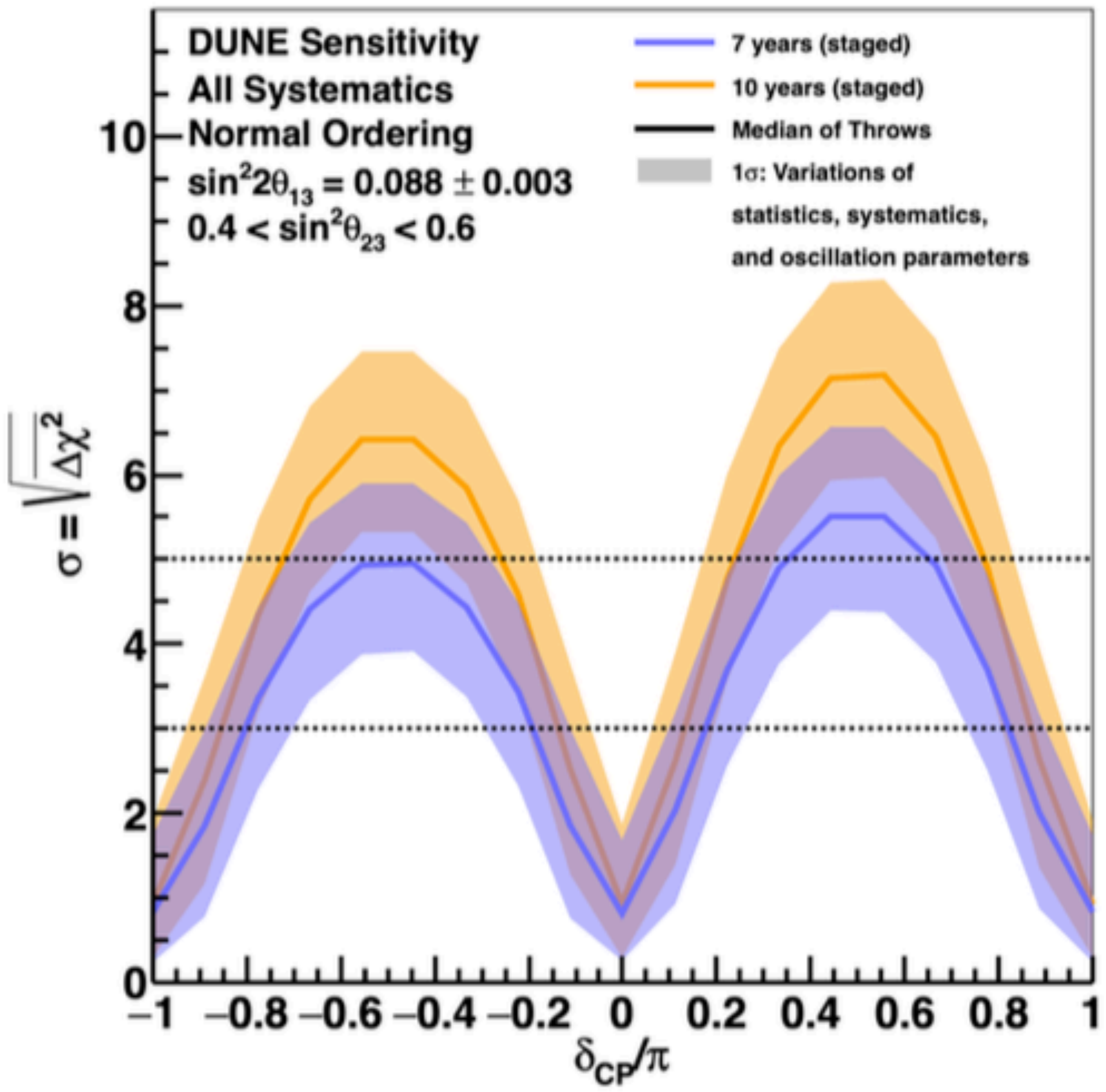


The DUNE Experiment.

DUNE's rich physics program

- The main physics goal of DUNE is to discover **CP violation** in the leptonic sector
  - within 3 years at $\delta_{cp} = \pi/2$
  - within 5 years 50% of δ_{cp} values (3σ)
  - $>5\sigma$ after 10 years running
- **Neutrino mass hierarchy** determination
  - 5σ within 2 years
- **Precise measurement of the PMNS** matrix parameters
  - Determination of the octant of θ_{23}

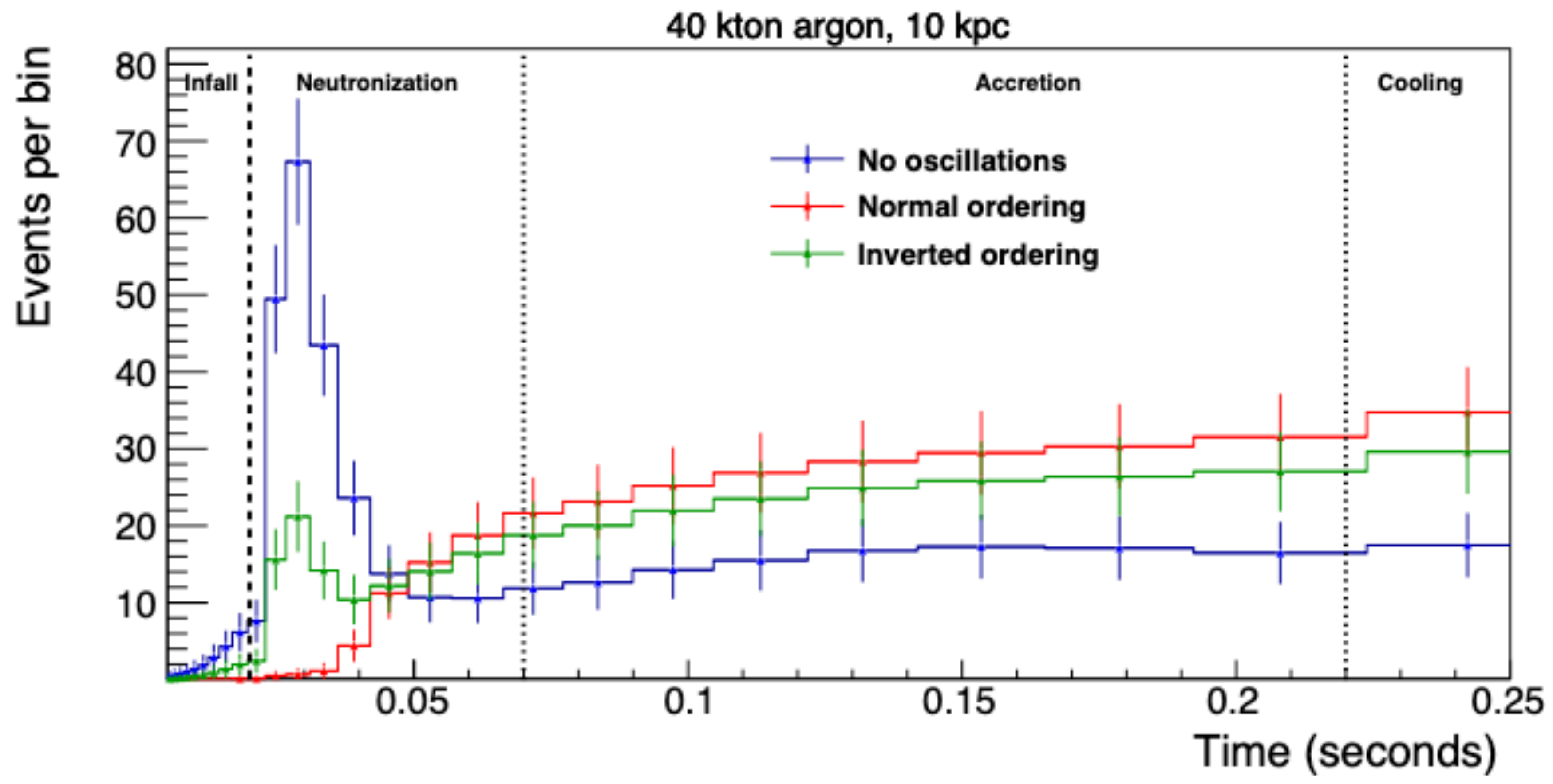


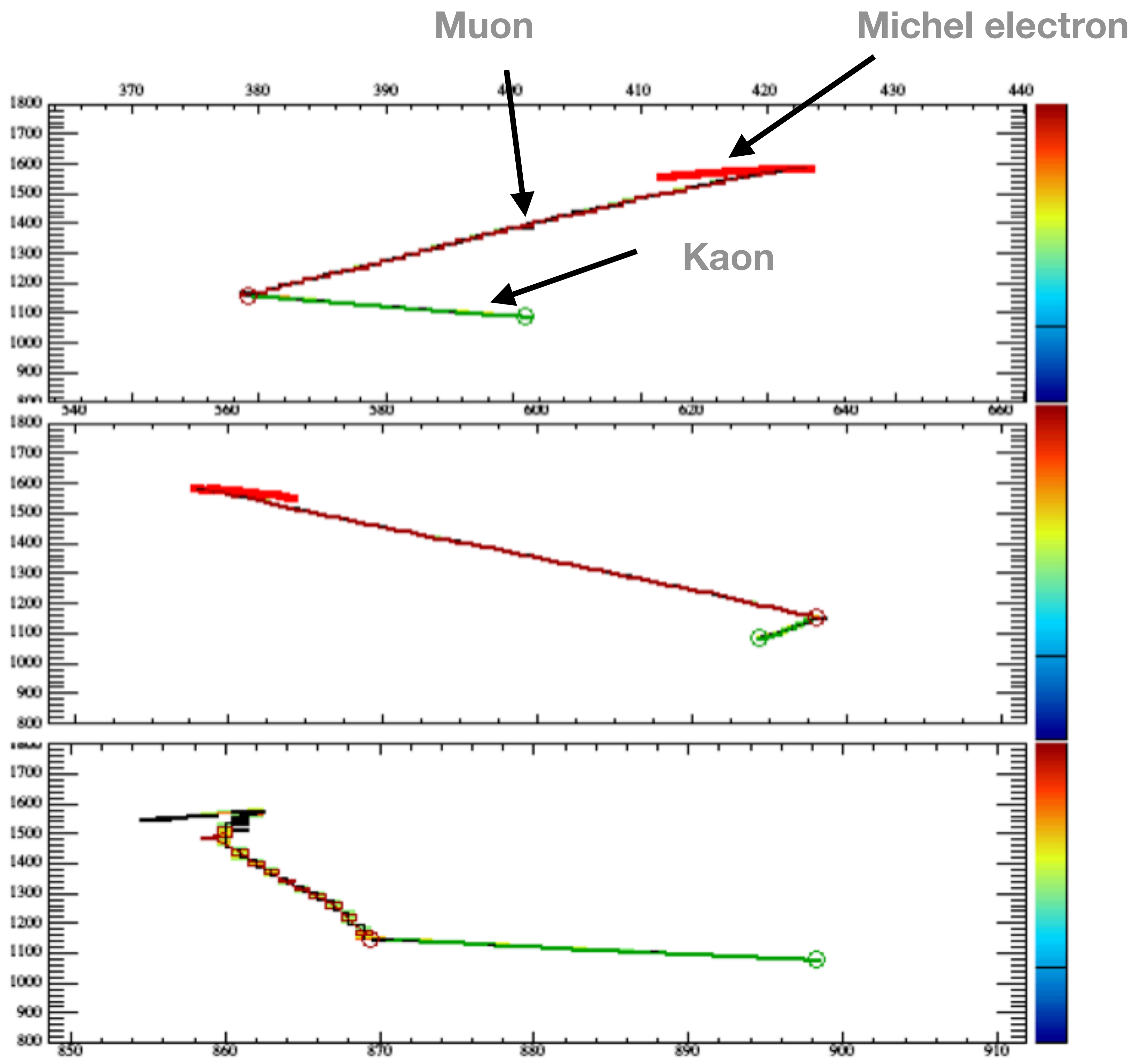


The DUNE Experiment.

DUNE's rich physics program

- Also a broad physics program
  - **Supernova neutrinos**
    - better understanding of the mechanisms in supernovas (collapse and evolution)
  - **Beyond the SM physics**
    - Nucleon decay searches (i.e. proton decay) ➠ baryon number violation ➠ insights in baryogenesis
    - Dark matter searches (WIMP)
    - ND-specific
      - Neutrino tridents ➠ rare weak process (Z' gauge boson)
      - Heavy Neutral Lepton
    - and more…





$p \rightarrow K^{+} + \bar{\nu}$

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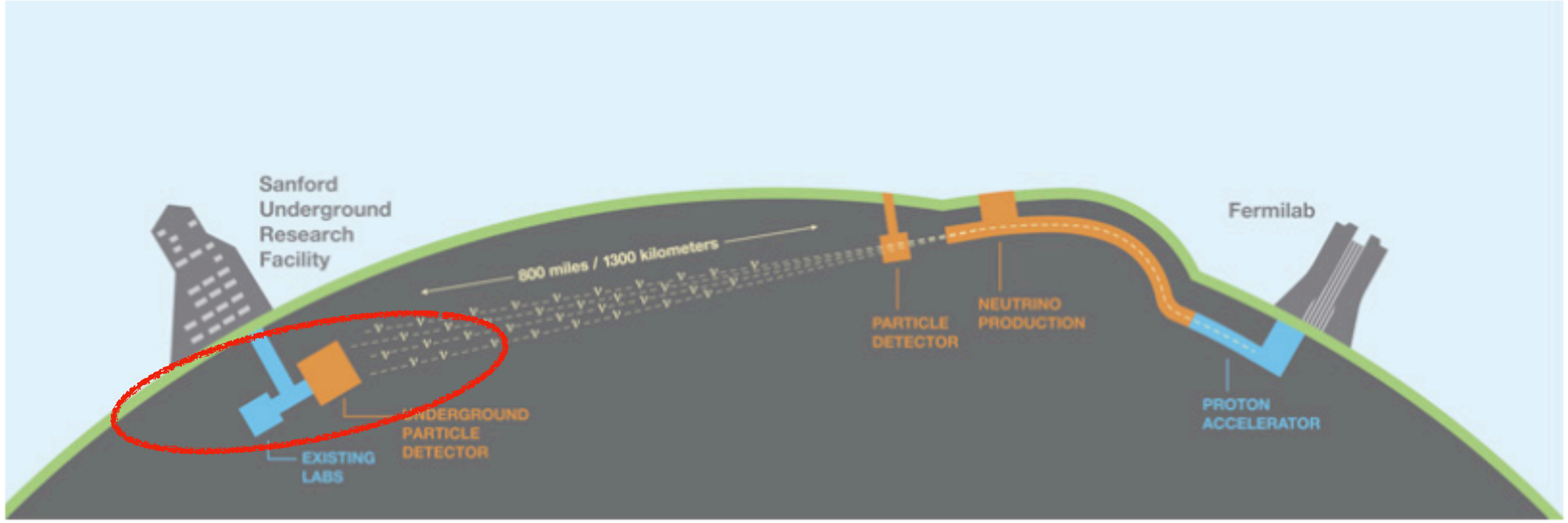
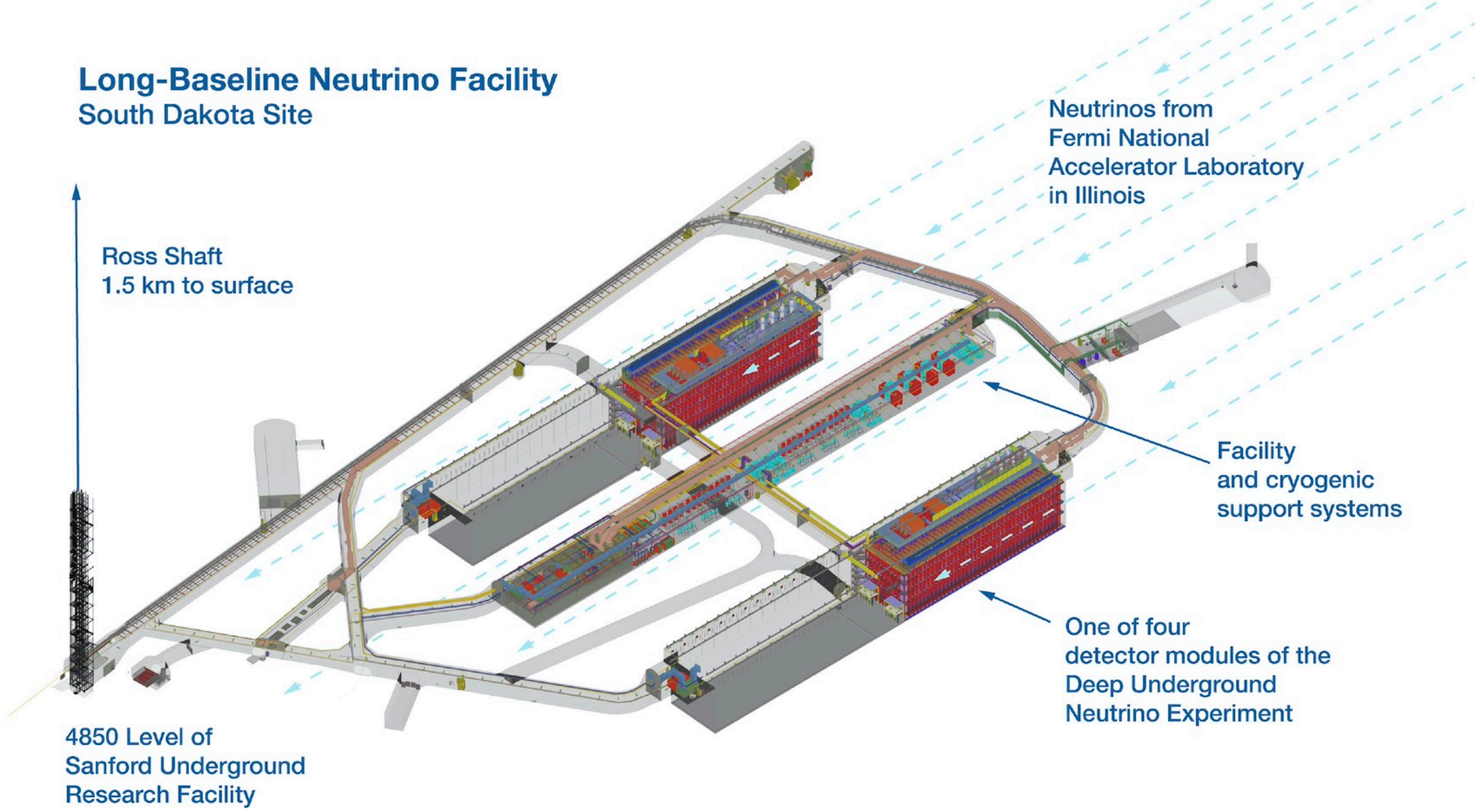


The DUNE Far Detector Complex.

Overview

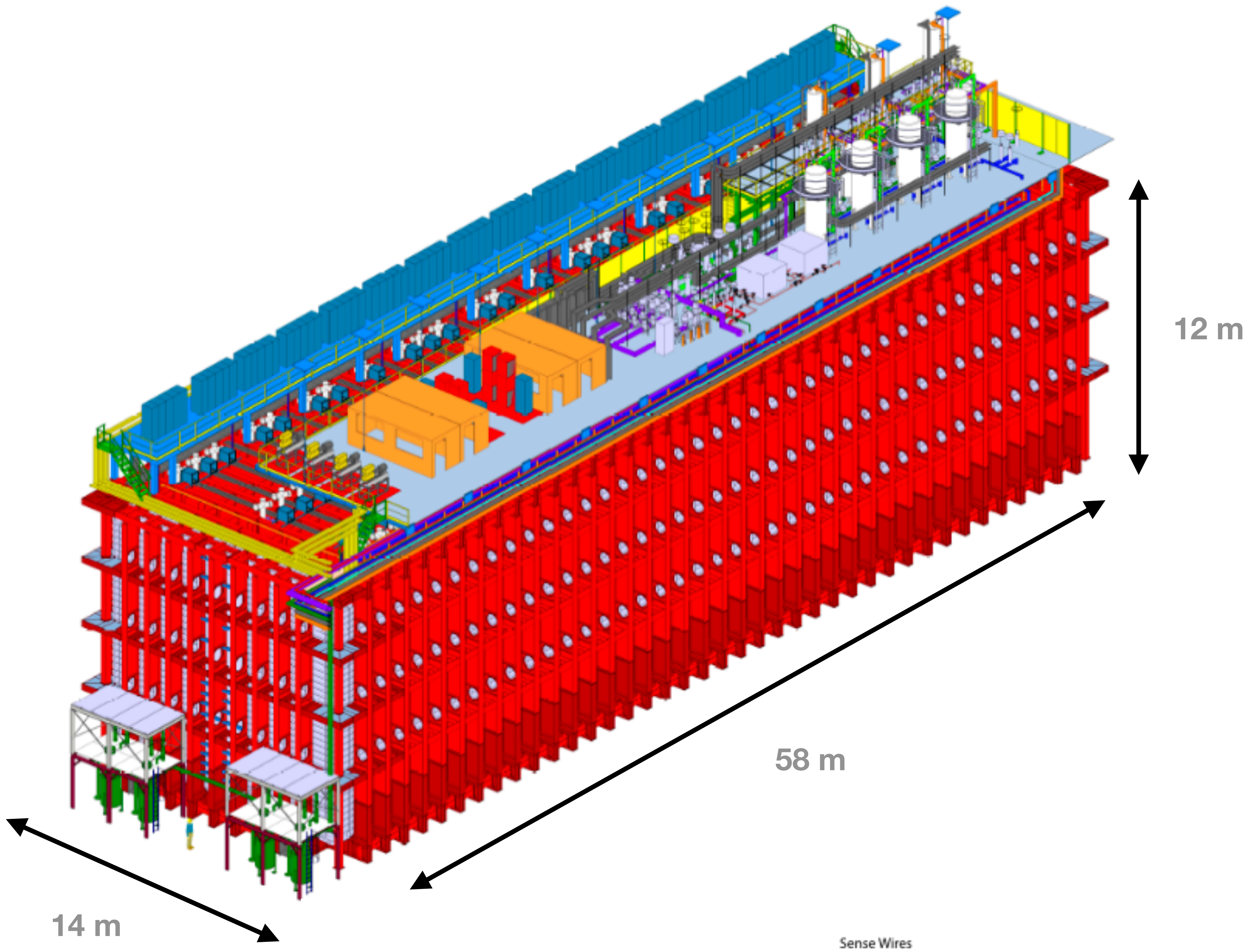
- South Dakota Laboratory at ~1300 km from Fermilab
  - Host already numerous experiments
    - LUX/LZ, Majorana
  - **Four 10-kt** Fiducial LAr TPC modules, located 1.48 km underground
- Excavation started in **2019**
- First module operational ~ **2026**
- Start of run:
  - 2 FD modules (20 kt), 1.2 MW beam power, with ND
- The detector modules are using different technologies
  - **Single Phase (SP)** liquid argon gas TPC
  - **Dual Phase (DP)** liquid argon gas TPC ➠ being phased out for a new technology **Vertical Drift**

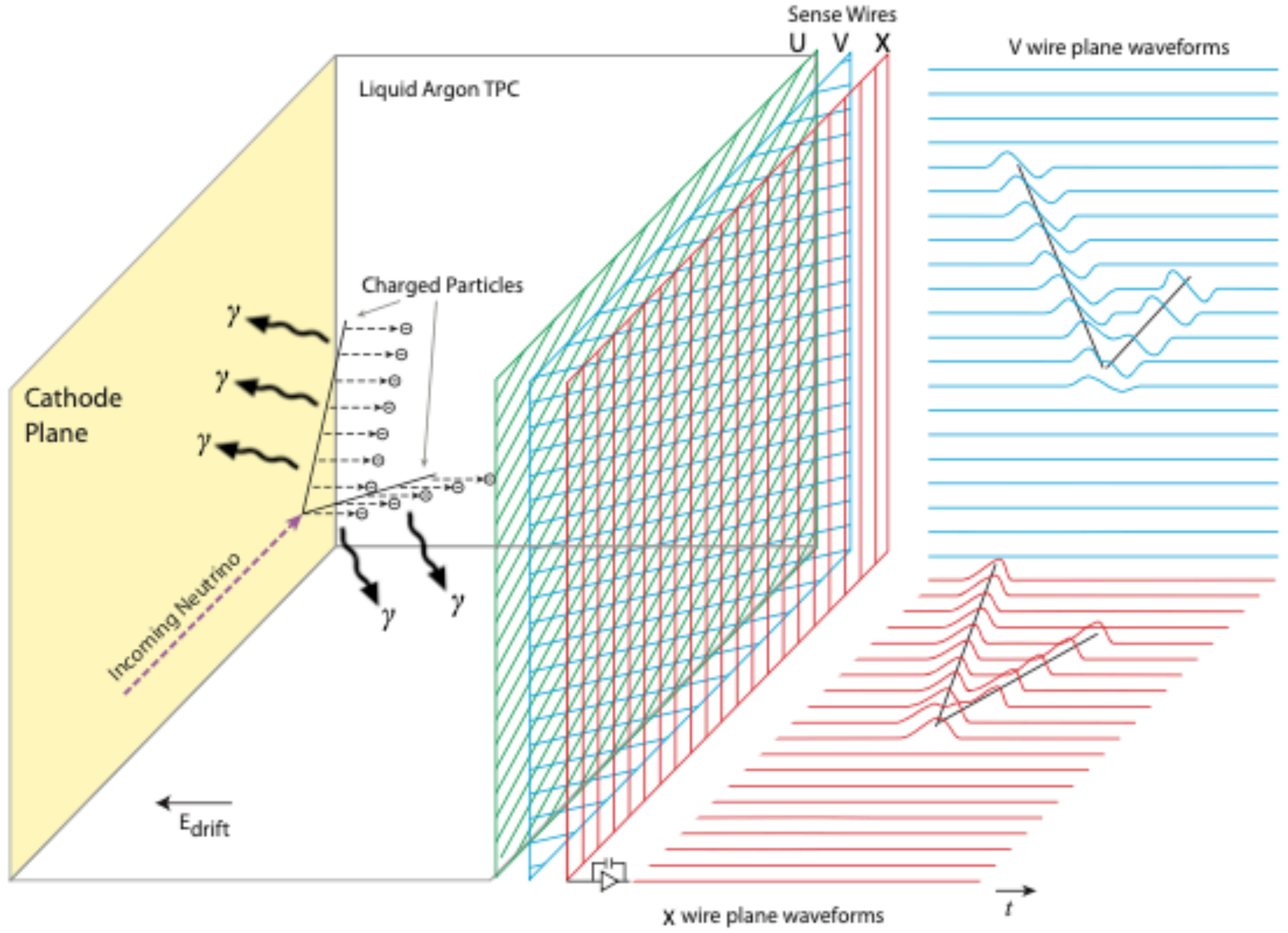


The DUNE Far Detector.

Single Phase technology (general overview)

- Based on general principles of LArTPCs demonstrated by numerous neutrino experiments (MicroBooNE, ArgoNeuT…)
  - ➠ Can **efficiently** track particles
  - ➠ Able to do **particle identification**
  - ➠ Provide **calorimetric** measurement of showers
  - ➠ **Fast scintillation** light to provide t_0
- *Push technological limits* in terms of size!!
- Drift between a cathode (*CPA*) and anode (*APA*) at a field of **250-500 V/cm**. Drift distance of **3.5m**
- Electrons are collected at the APAs by *3 wire-planes* (1 collection, 2 induction)
- Photons (127 nm) are collected by photon detectors (*ARAPUCA*) mounted on the APA frames

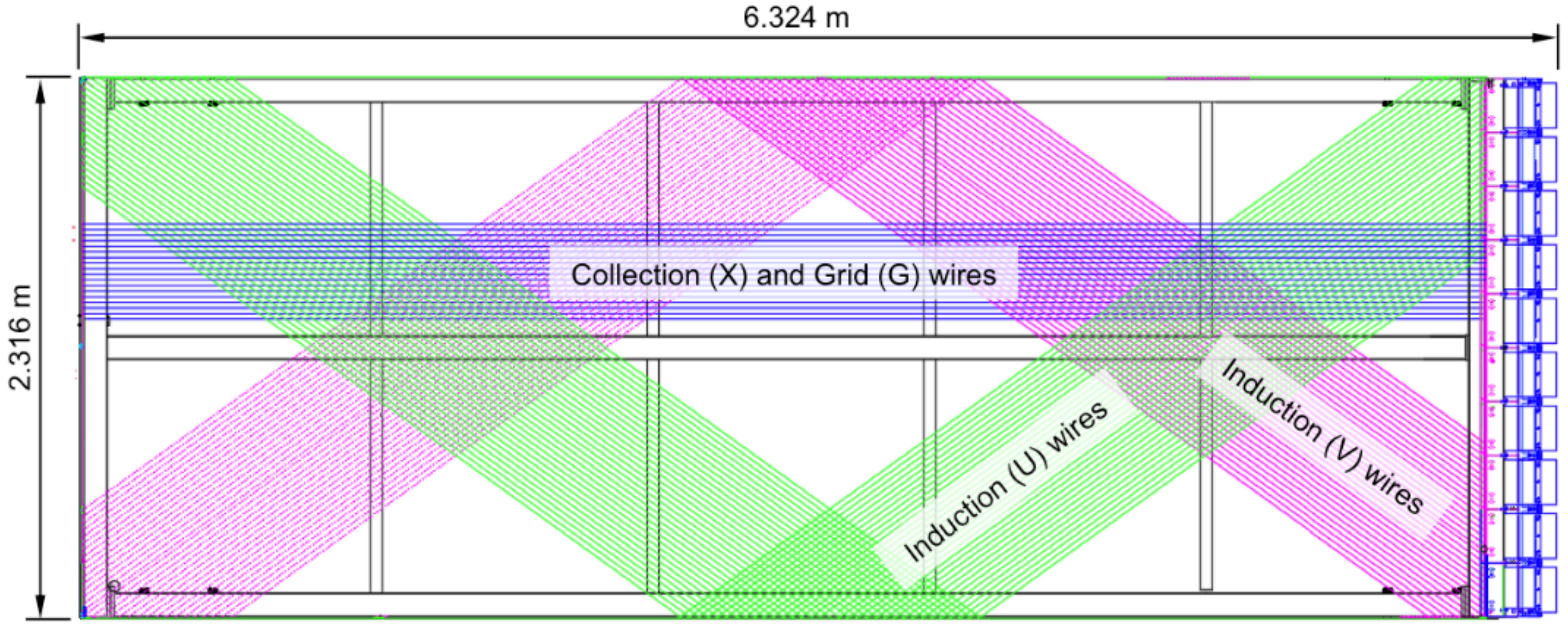


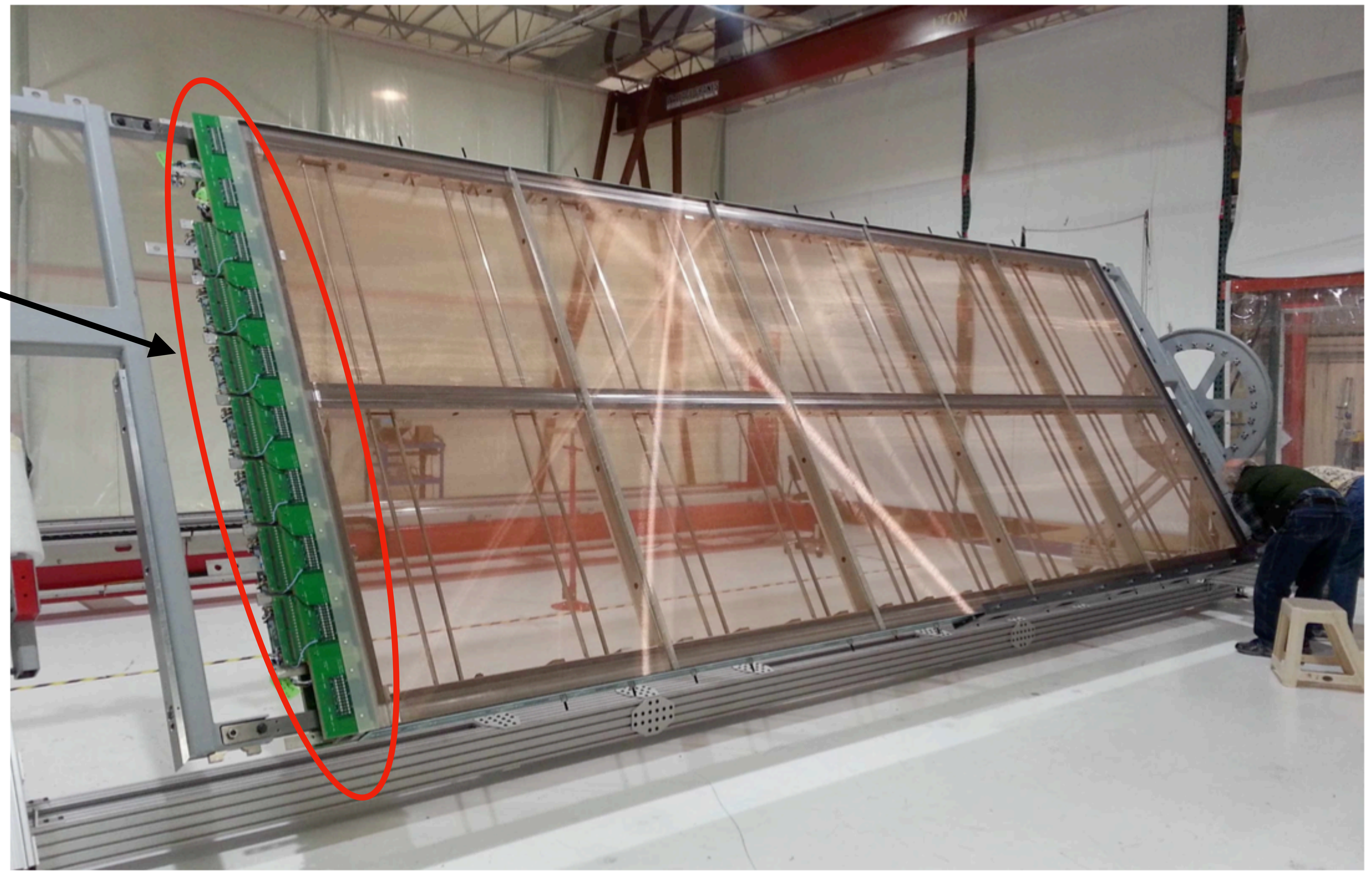


The DUNE Far Detector.

Single Phase technology (APAs, CPAs, Photodetectors)

- The anode planes (APA) are 6 m x 2.3 m (HxW)
  - 25 modules for a full plane. *150 APA* in total
- Covered by more than 2500 sense wires (~5 mm pitch) laid in 3 orientations ➠ **375k channels**
  - Vertical collection plane (X), +/- 37.5 deg from vertical (U/V) induction planes
- All wires are read out on one end of the APAs
- Requirements
  - **Transparency** to the light
  - **Minimum dead areas**
  - **Support** for the PD, routing cables for the electronics





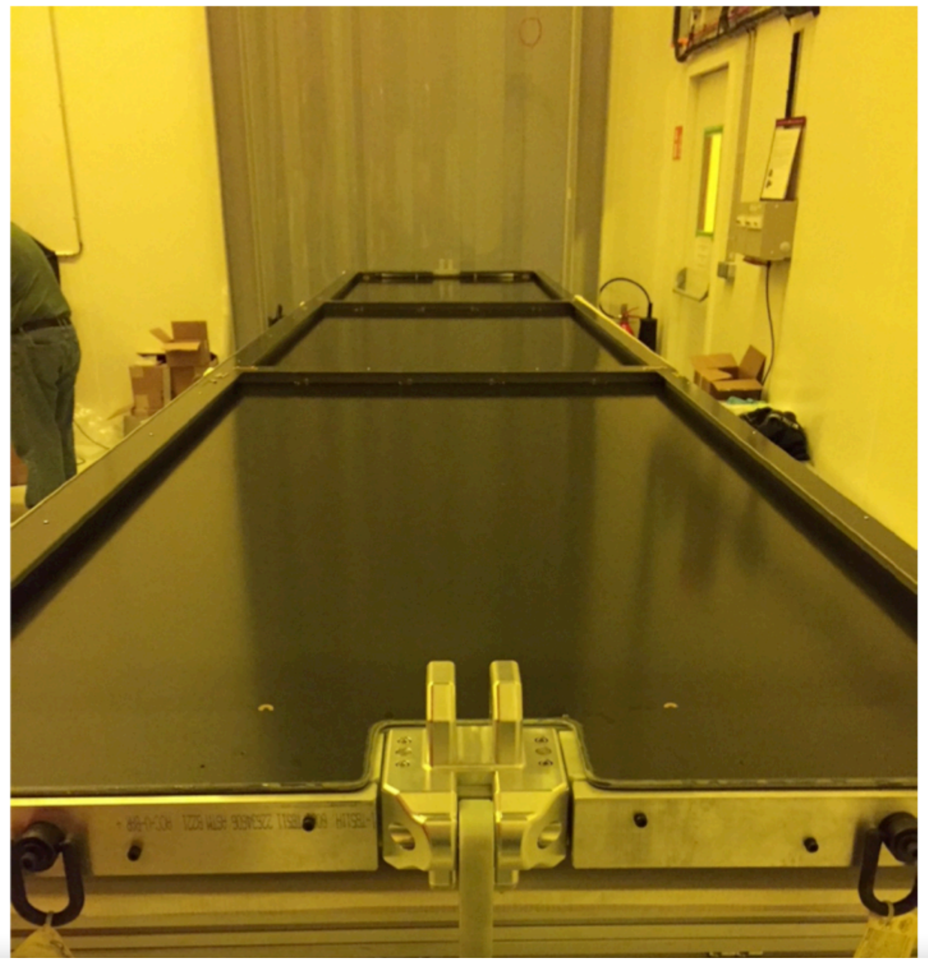
Final APA Module

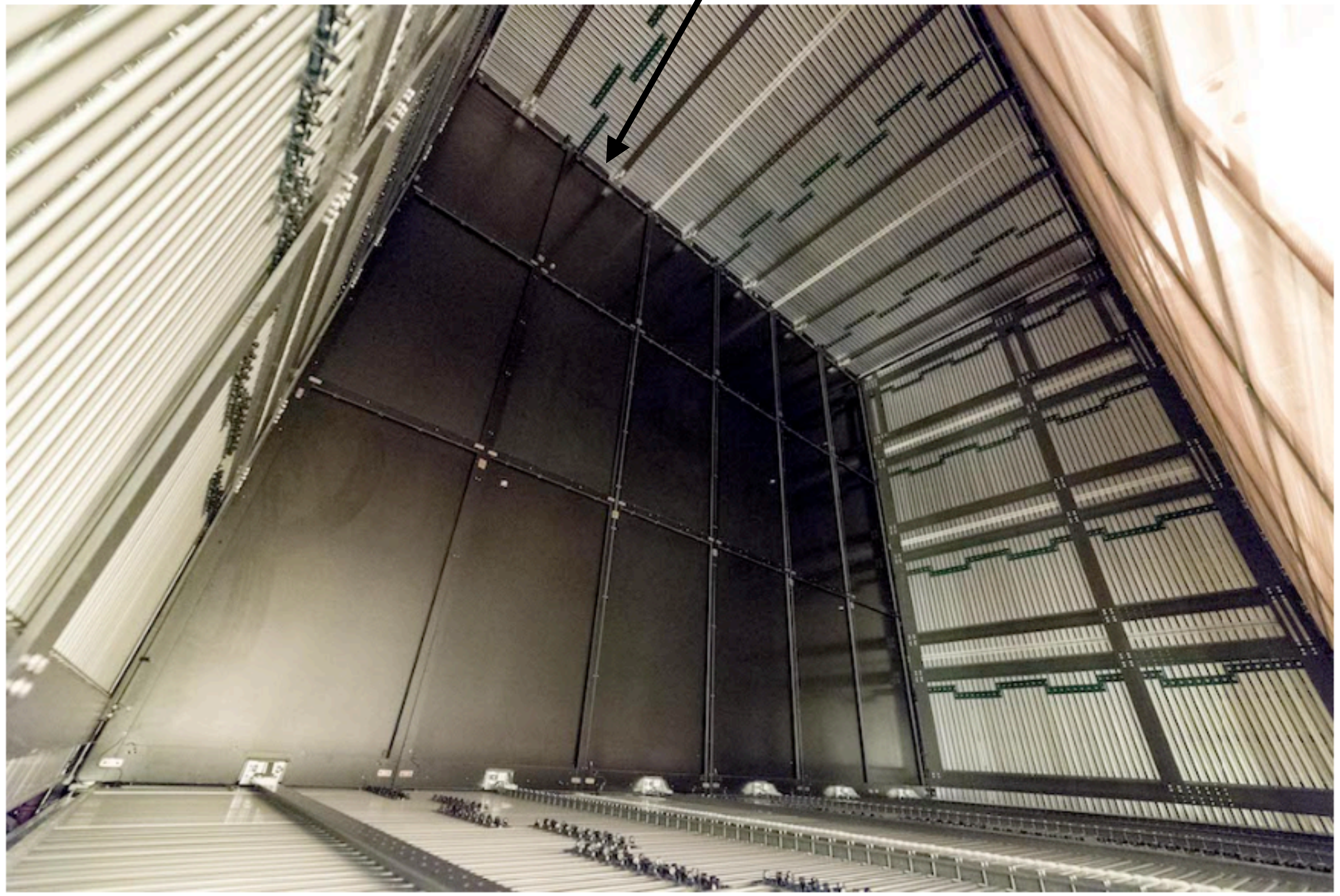
The DUNE Far Detector.

Single Phase technology (APAs, CPAs, Photodetectors)

- The cathode unit are 4 m x 1.2 m assembled in panels (3) then into planes (2)
  - A CPA array consists of 25 planes ➠ in total ~**600 CPA** units
- Cathode plane at -180 kV
- Requirements
  - Drift field of **> 250 V/cm** (Goal of 500 V/cm)
  - **<1% field non-uniformity**
  - HV **Stability** (Protection against sparks, discharges)
- Very complex system
  - Power supply, feedthroughs, mechanics

Full CPA assembled





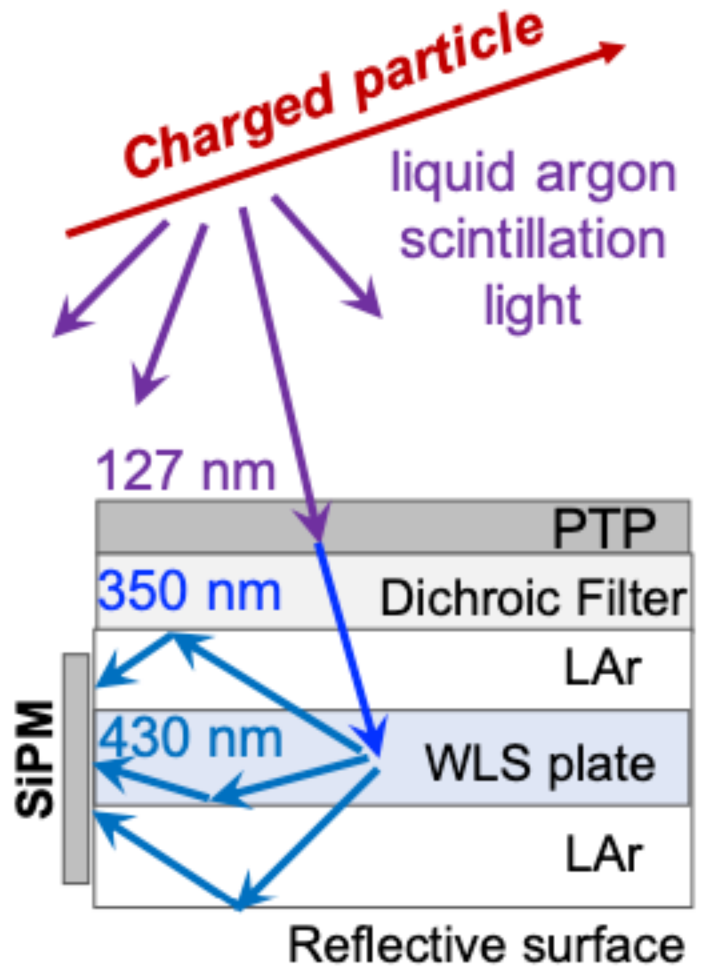
Final CPA Plane in ProtoDUNE

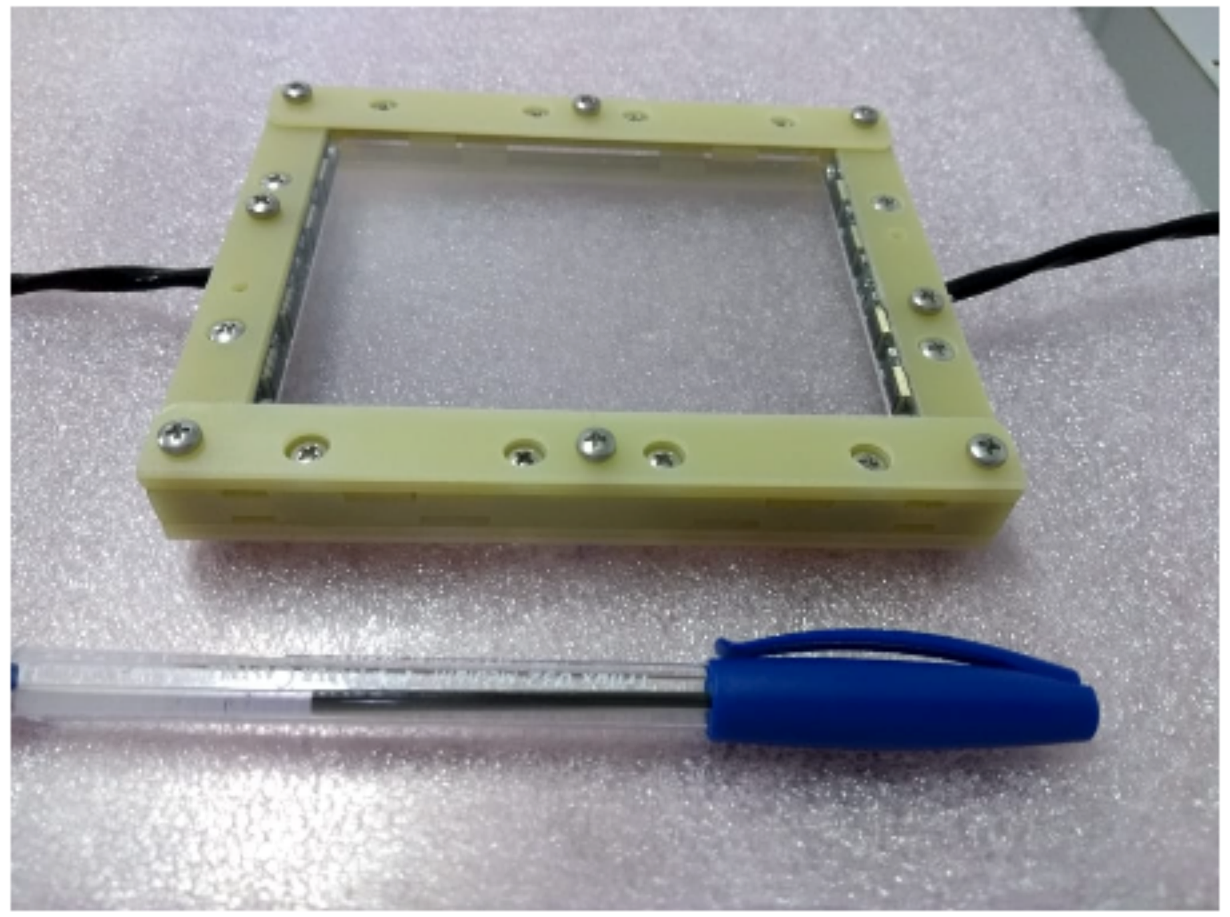
CPA array in ProtoDUNE prototype

The DUNE Far Detector.

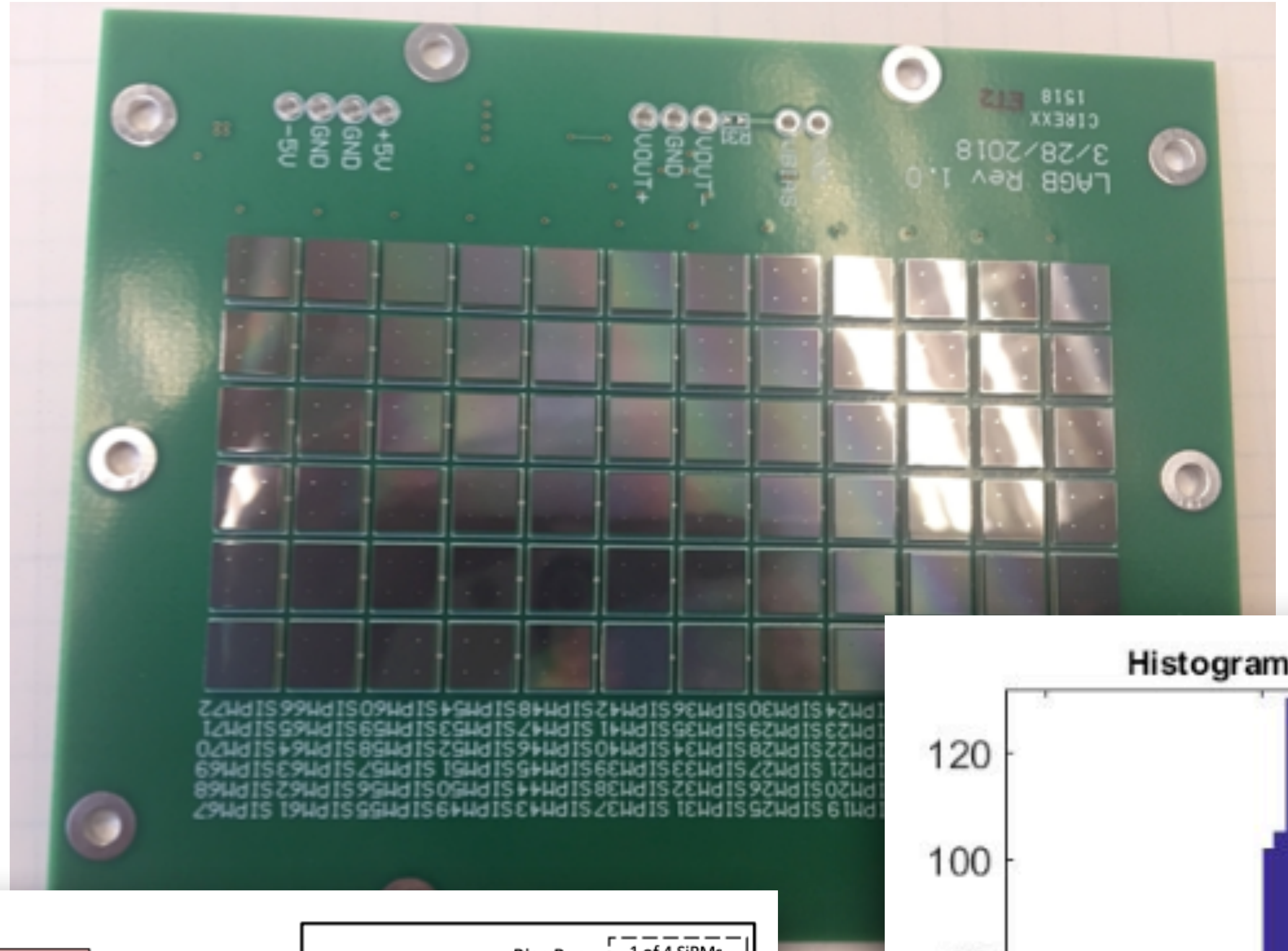
Single Phase technology (APAs, CPAs, Photodetectors)

- A system of PD are installed inside the APAs to detect light (**ARAPUCA**)
  - 10 modules per APA (1500 total)
  - SiPM from Hamamatsu: 6x6 mm2 (**288k in total**)
  - Total number of channels: **6k**
- Very interesting **light shifting and trapping system**
  - Use properties of different materials to shift the wavelength and trap the photons
- Readout
  - Active/Passive *ganging* of the SiPMs (6x8)
  - FEB designed for Mu2e with off-the-shell components: Spartan 6 FPGA, ultrasound chips…
  - Up to *64 channels*, *~120 mW per channel*
  - Max data rate: *10 MB/s* per FEB (24/APA)

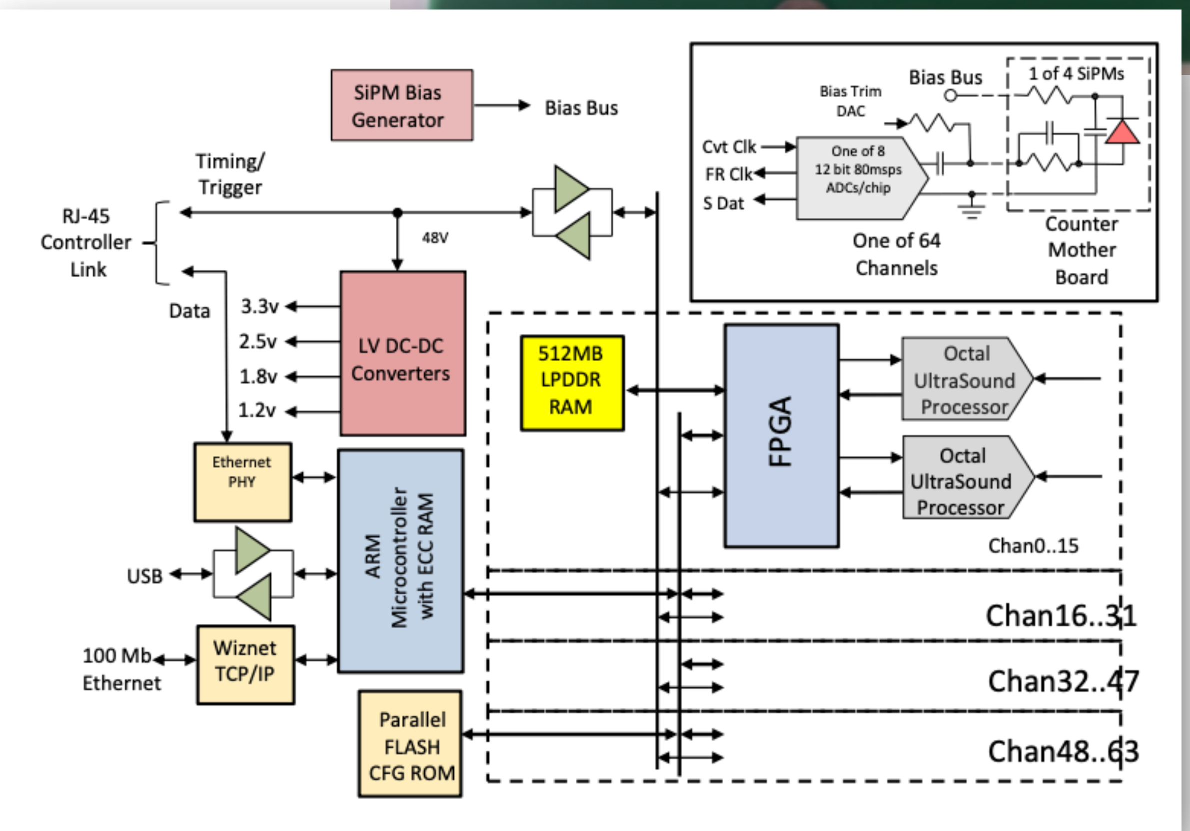


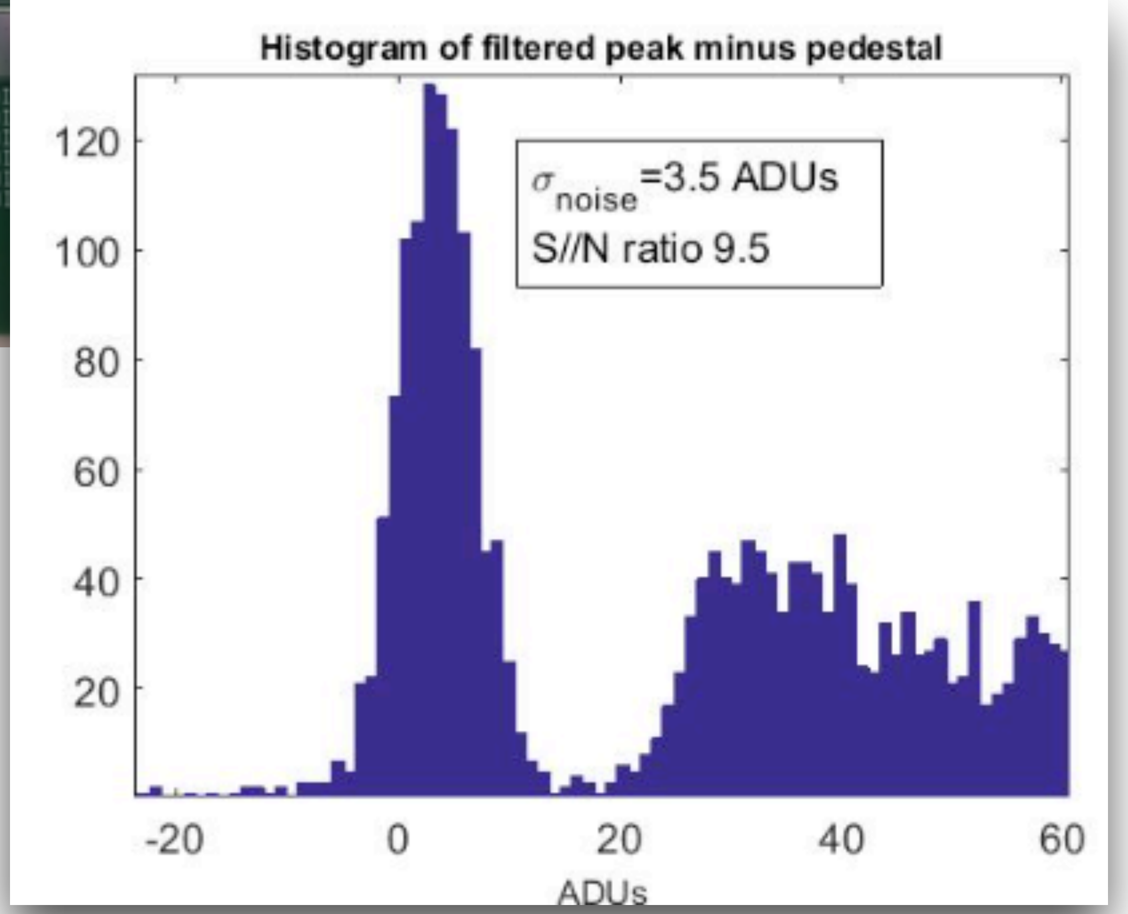


ARAPUCA device



Test of the ganging of 72 SiPM

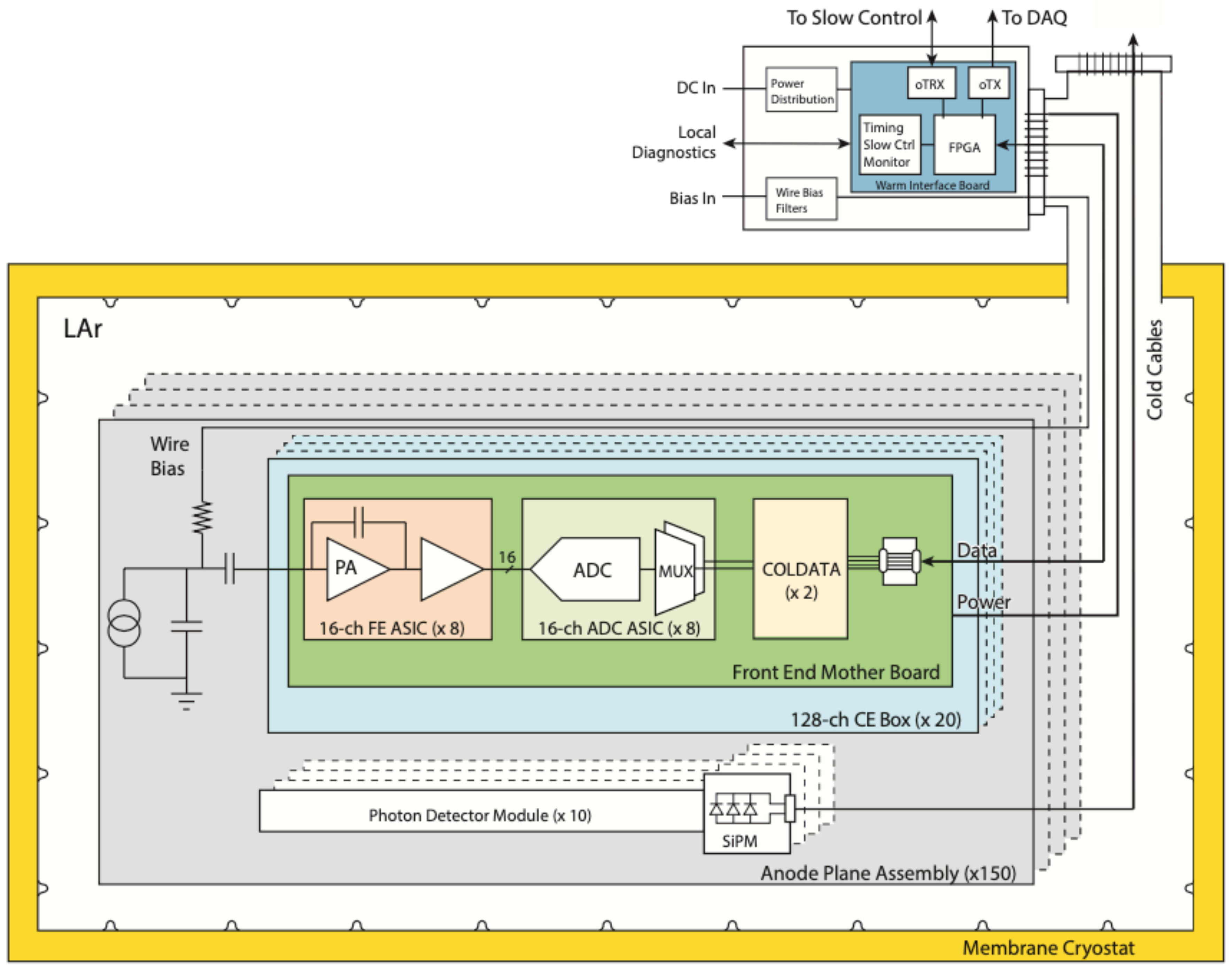


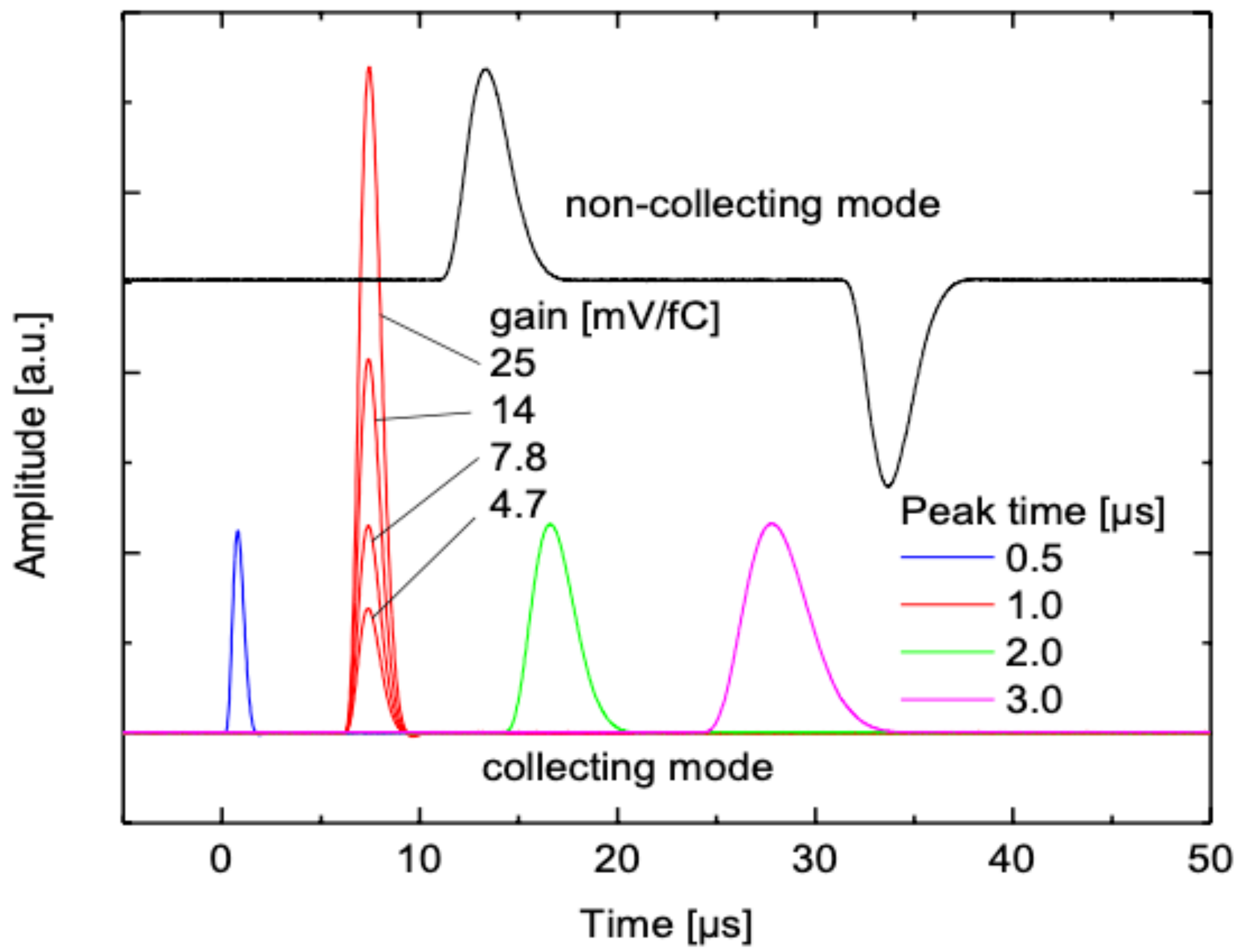


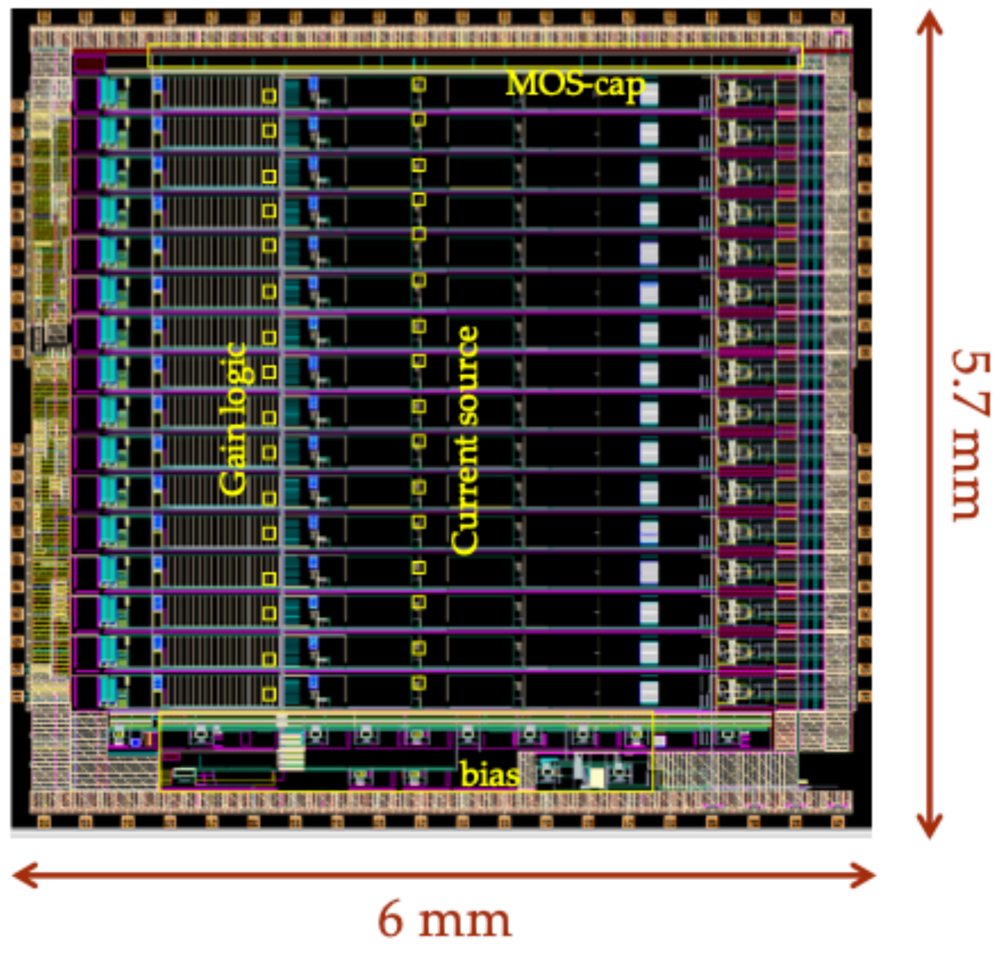
The DUNE Far Detector.

Single Phase technology (TPC Electronics)

- The FE is placed **inside** the cryostat (better for S/N and less cables going in/out)
  - **Low noise** is essential (no amplification in the LAr)
  - Provides **full waveform** sampling
- 2500+ APA channels are collected by 20 FEMBs, digitized and send out (**128 channels per FEMB**)
- 3 reference designs for the ASICs (LArASIC, ColdASIC, COLDATA)
  - No access inside the cryostat ➟ need to live the **full lifetime** of the experiment!
  - Imposes *technological choices and constrains* in LAr (**hot-carrier effect**)
  - Careful tests in LAr are carried out for any commercial circuits
- Readout bandwidth specifications
  - Cold ↔ Warm ~ **5 Gbps/FEMB**
  - Warm ↔ backend ~ **10 Gbps/link** (FELIX)



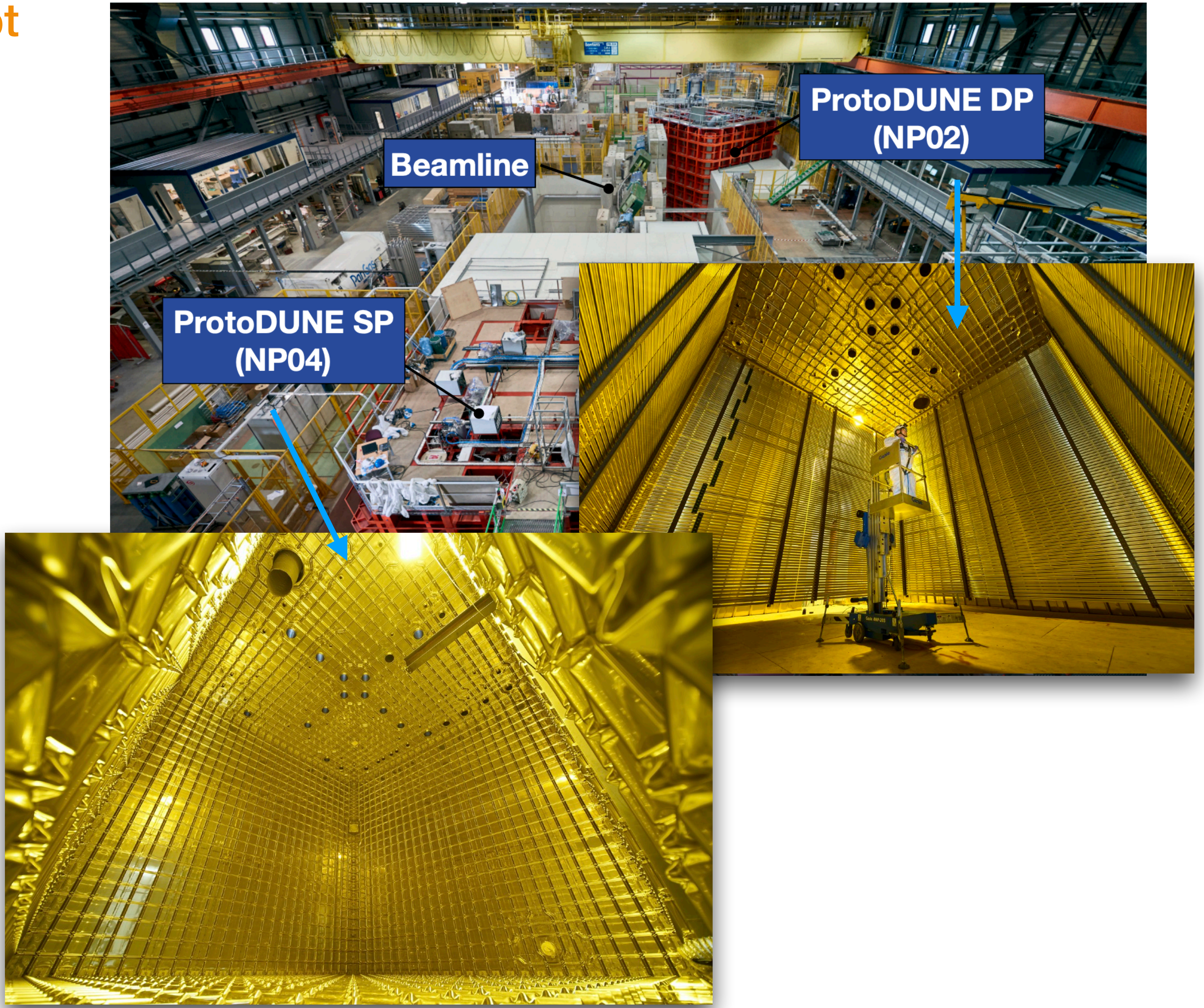




The DUNE Far Detector.

ProtoDUNE SP Prototype, a proof of concept

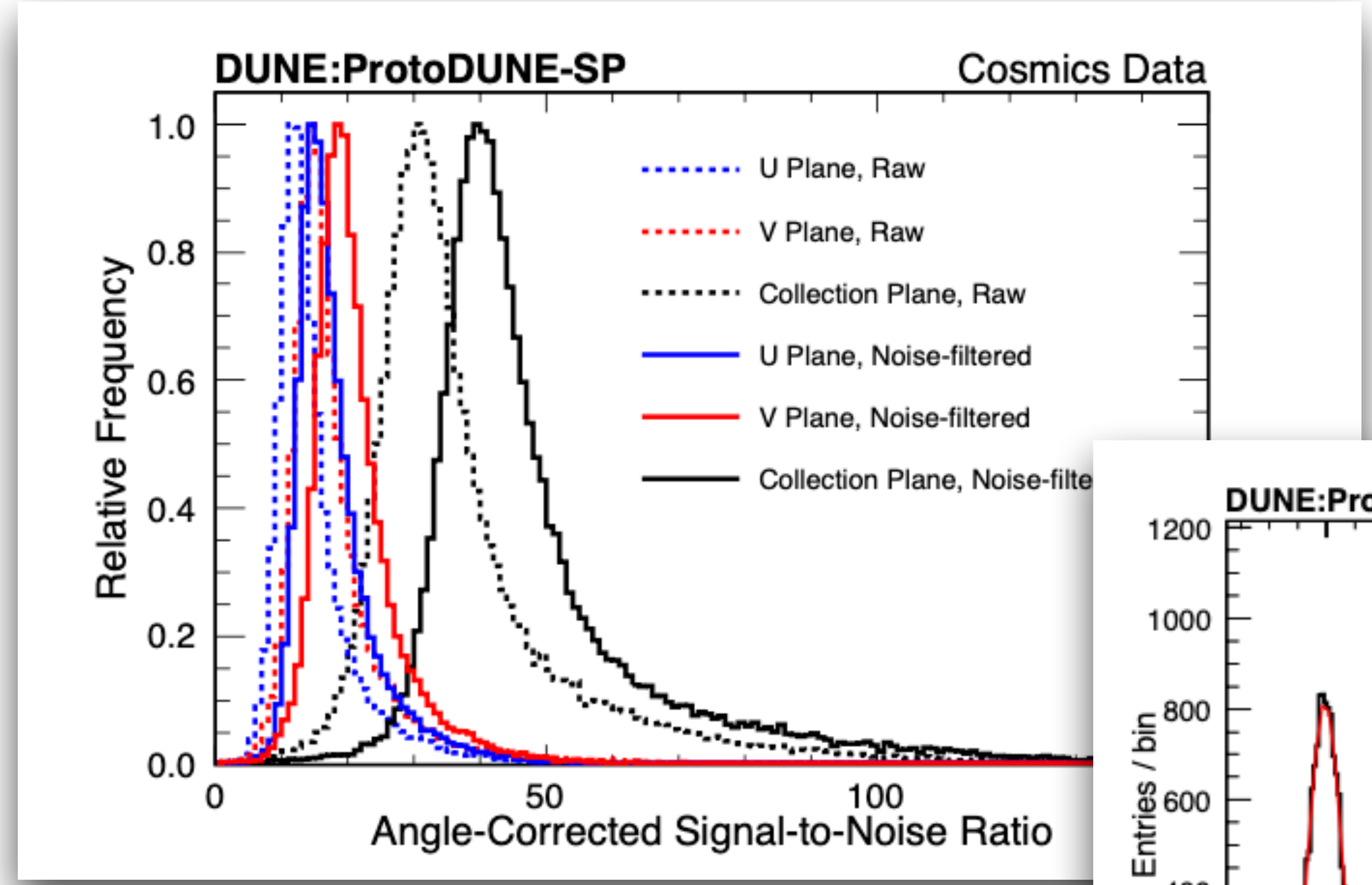
- To validate the technical choices ➠ prototype(s) built called **ProtoDUNE**
- Built at the Neutrino Platform at CERN in the North Hall Area
- Two prototypes: SP/DP (see next slides)
- SP finished in summer 2018
  - 6x7x7 m3, **0.77 kT FV**
  - Took data before shutdown
- DP finished in June/July 2019
  - 6x6x6 m3, **300t FV**
  - Took cosmic ray data
- ➠ **Largest monolithic LArTPCs in the world**

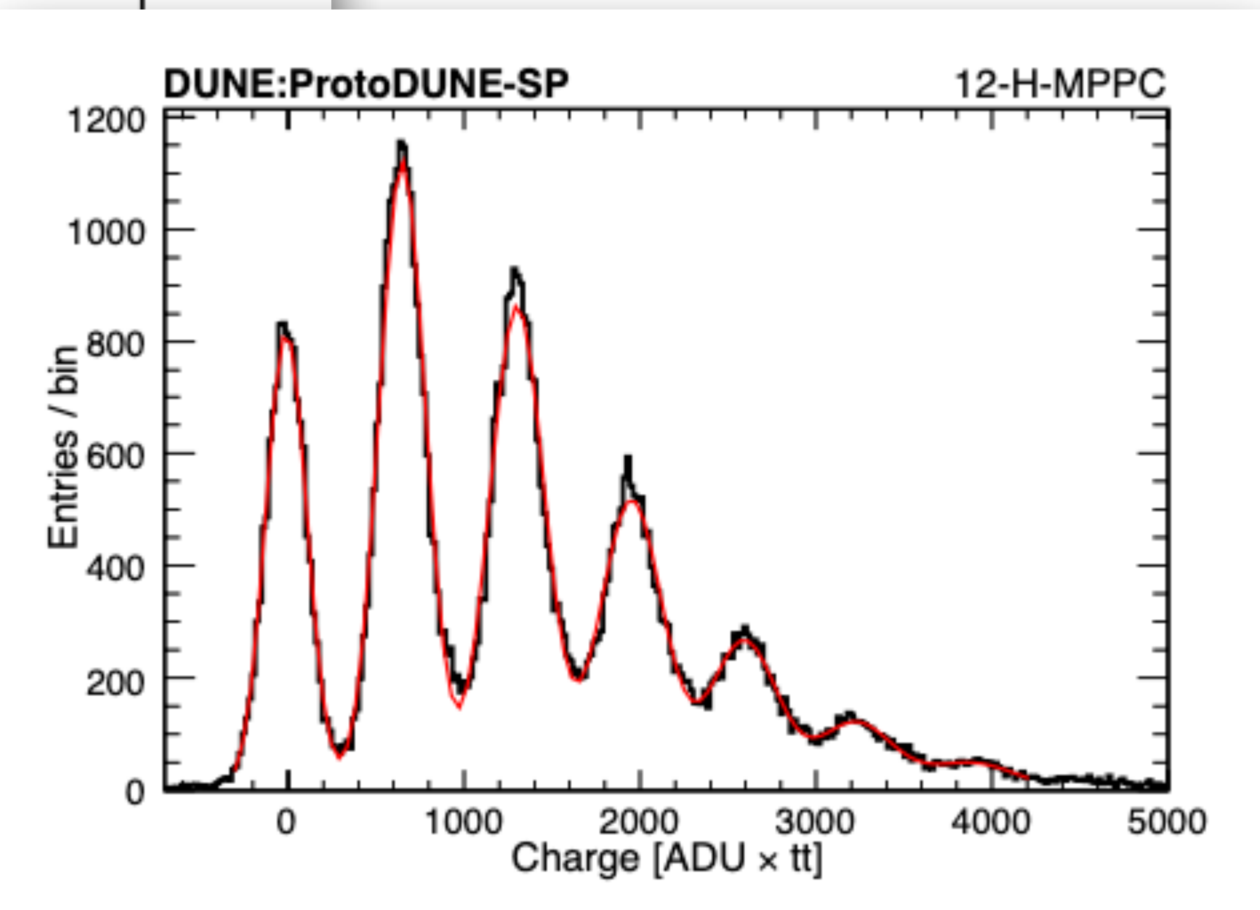


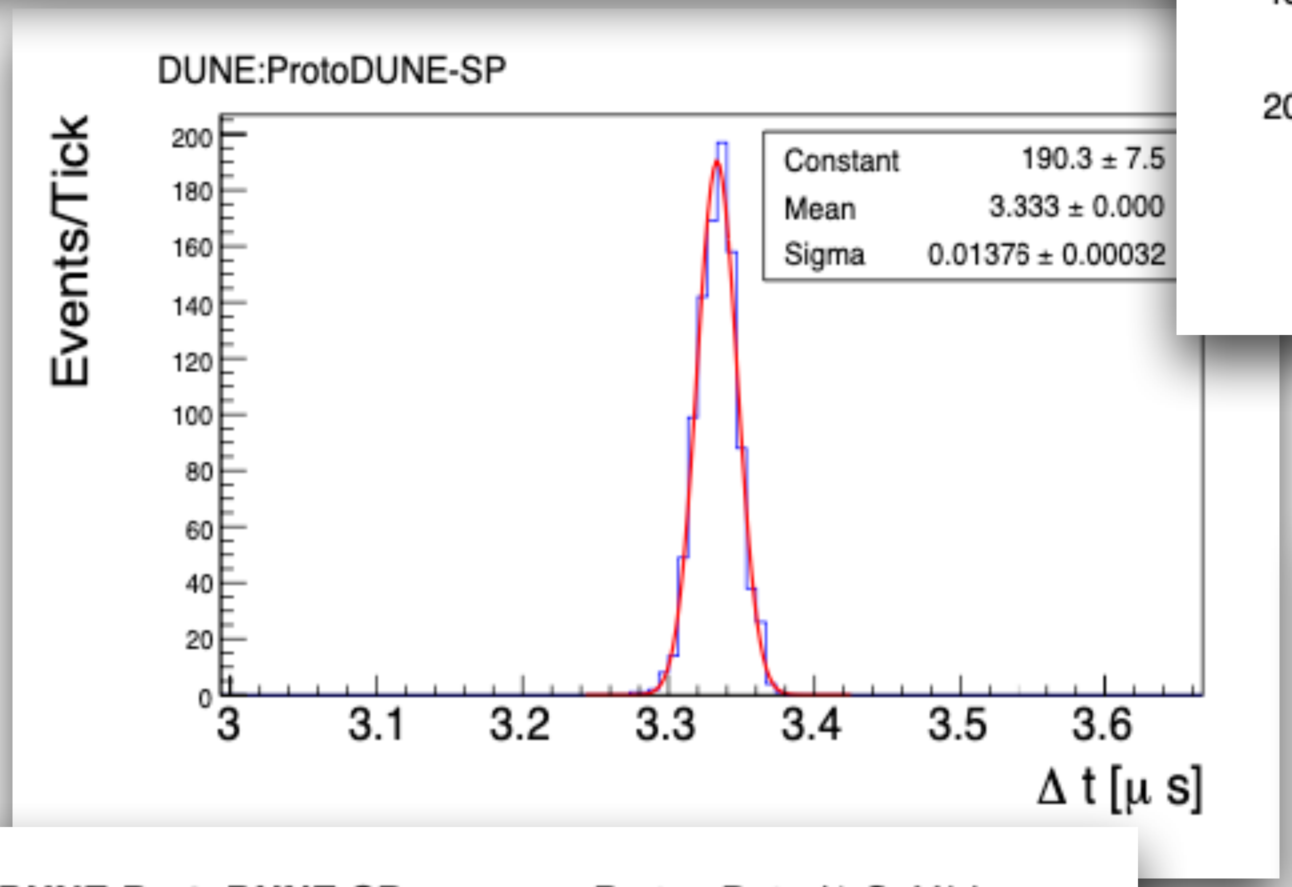
The DUNE Far Detector.

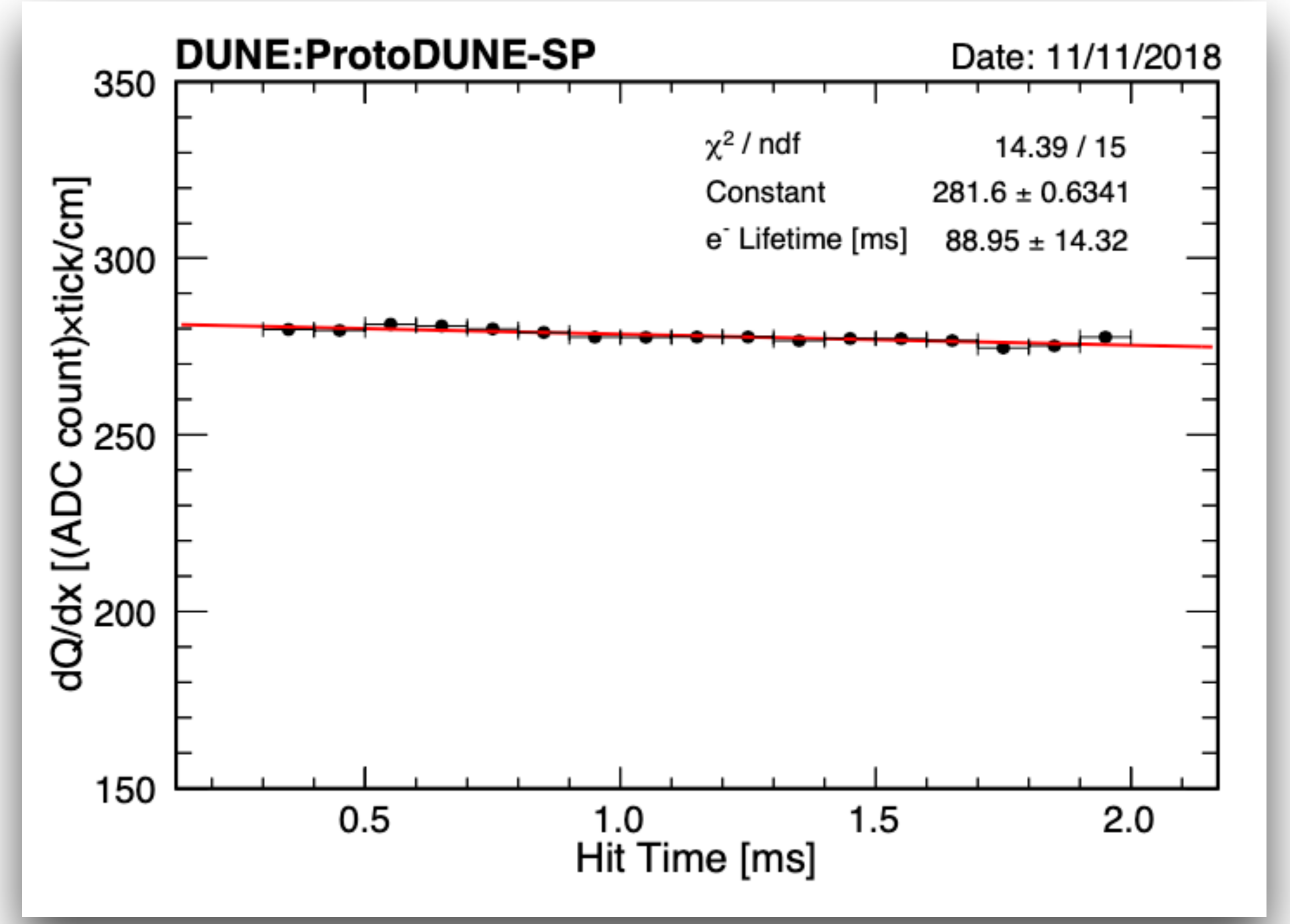
ProtoDUNE SP Prototype, a proof of concept

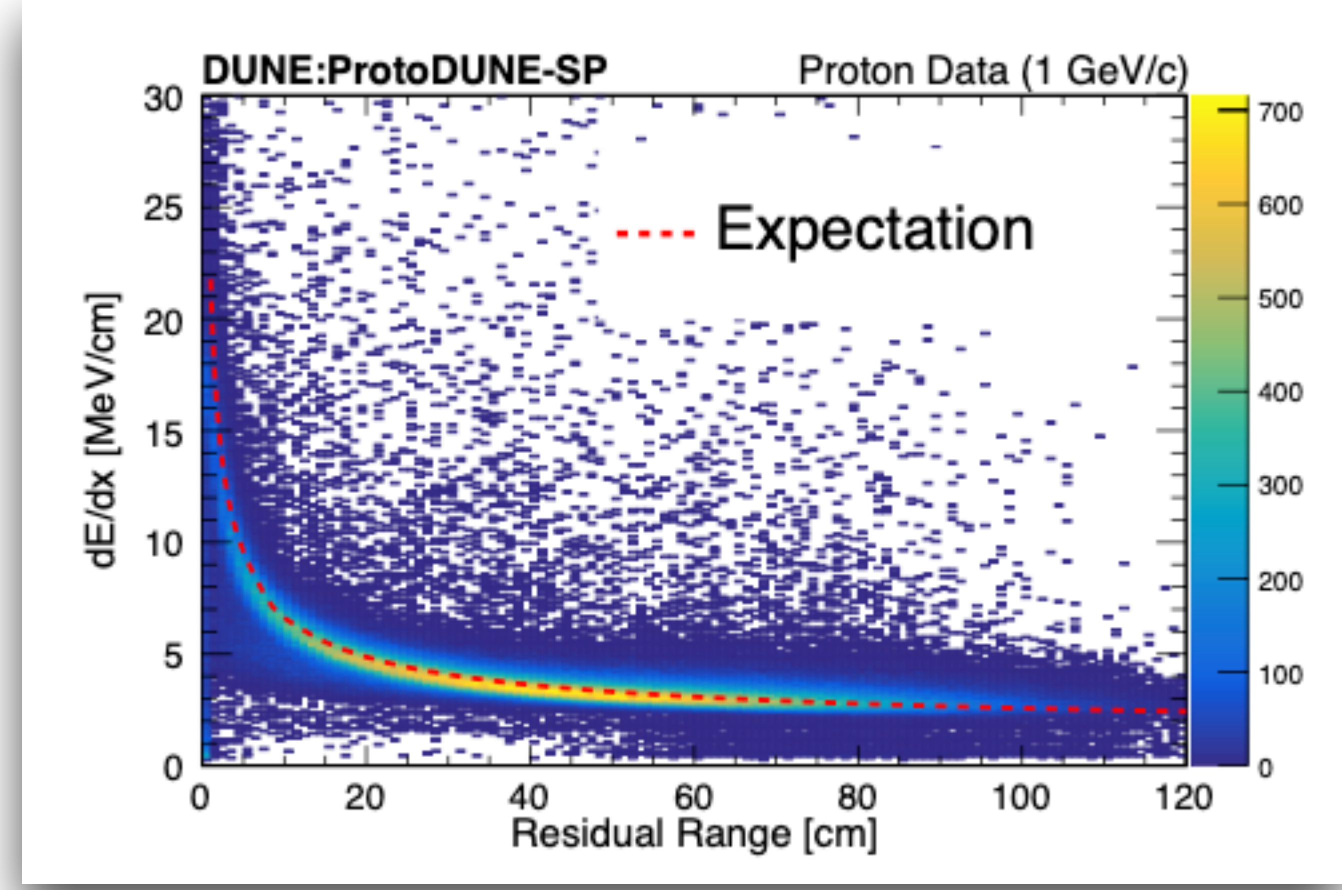
- First results very promising
- Low noise on all readout planes
- S/N over **10** (induction planes), **> 40** for collection plane
- Very stable running since 2018
  - Very good electron lifetime
  - Stable HV/electronics
- Very good PD performance, timing resolution **~15 ns**

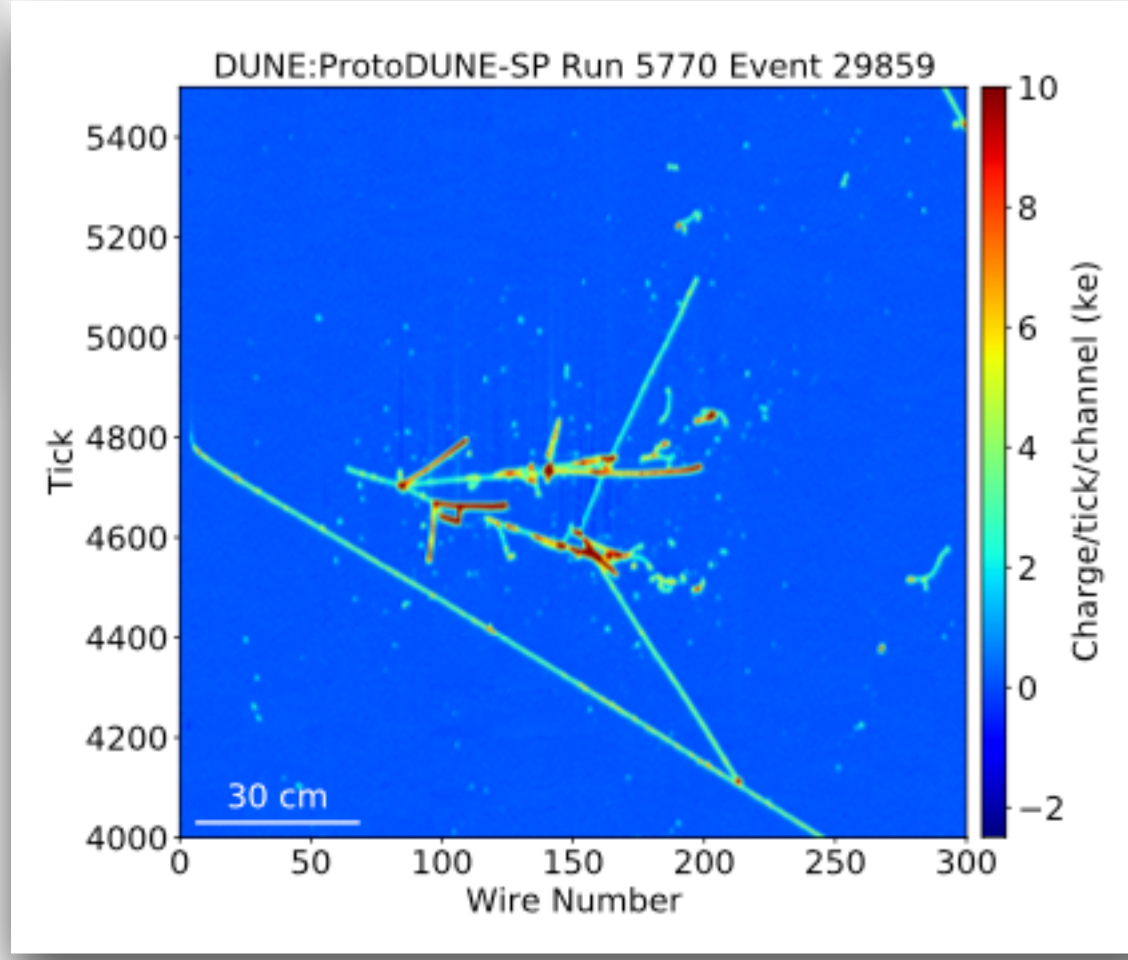








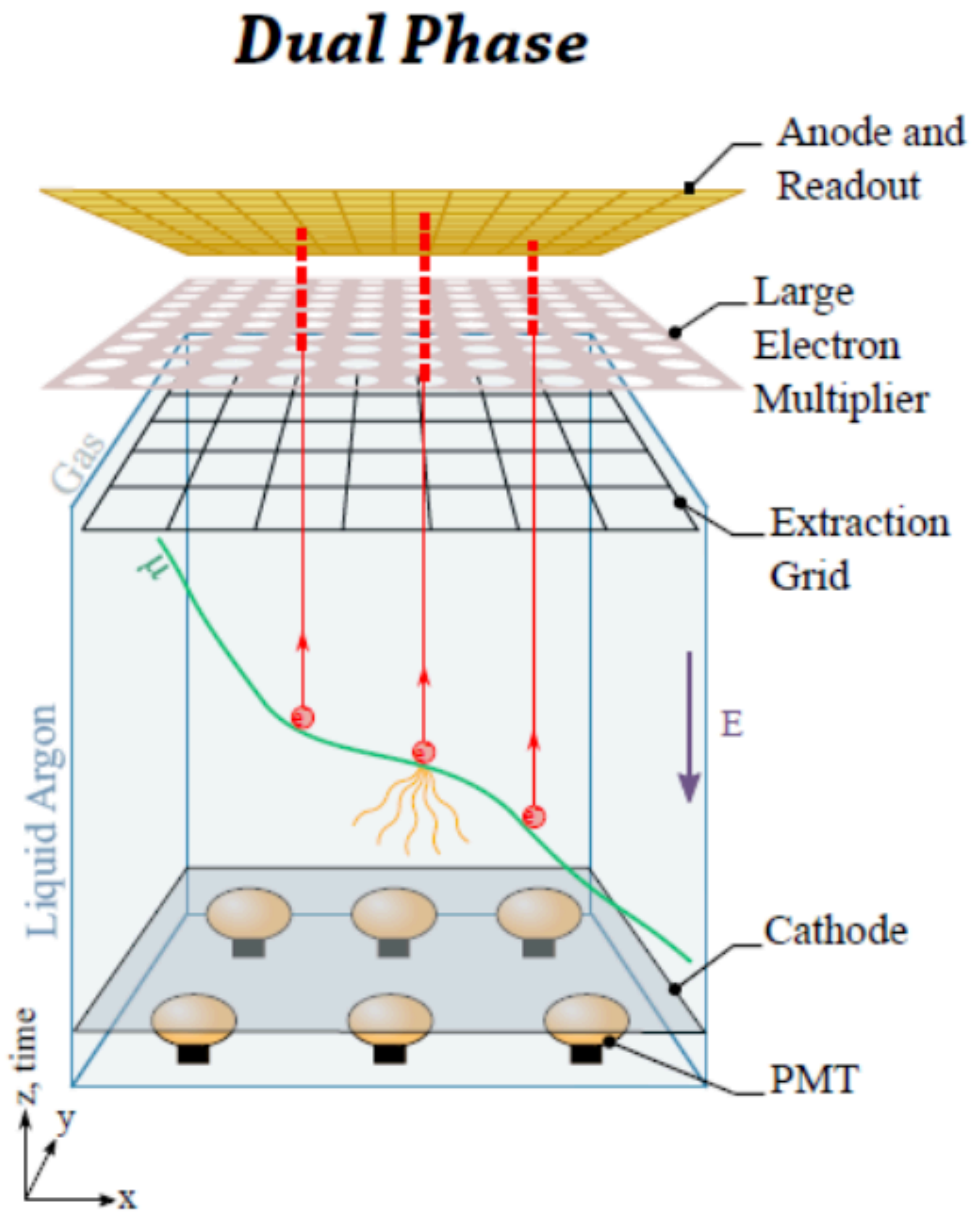


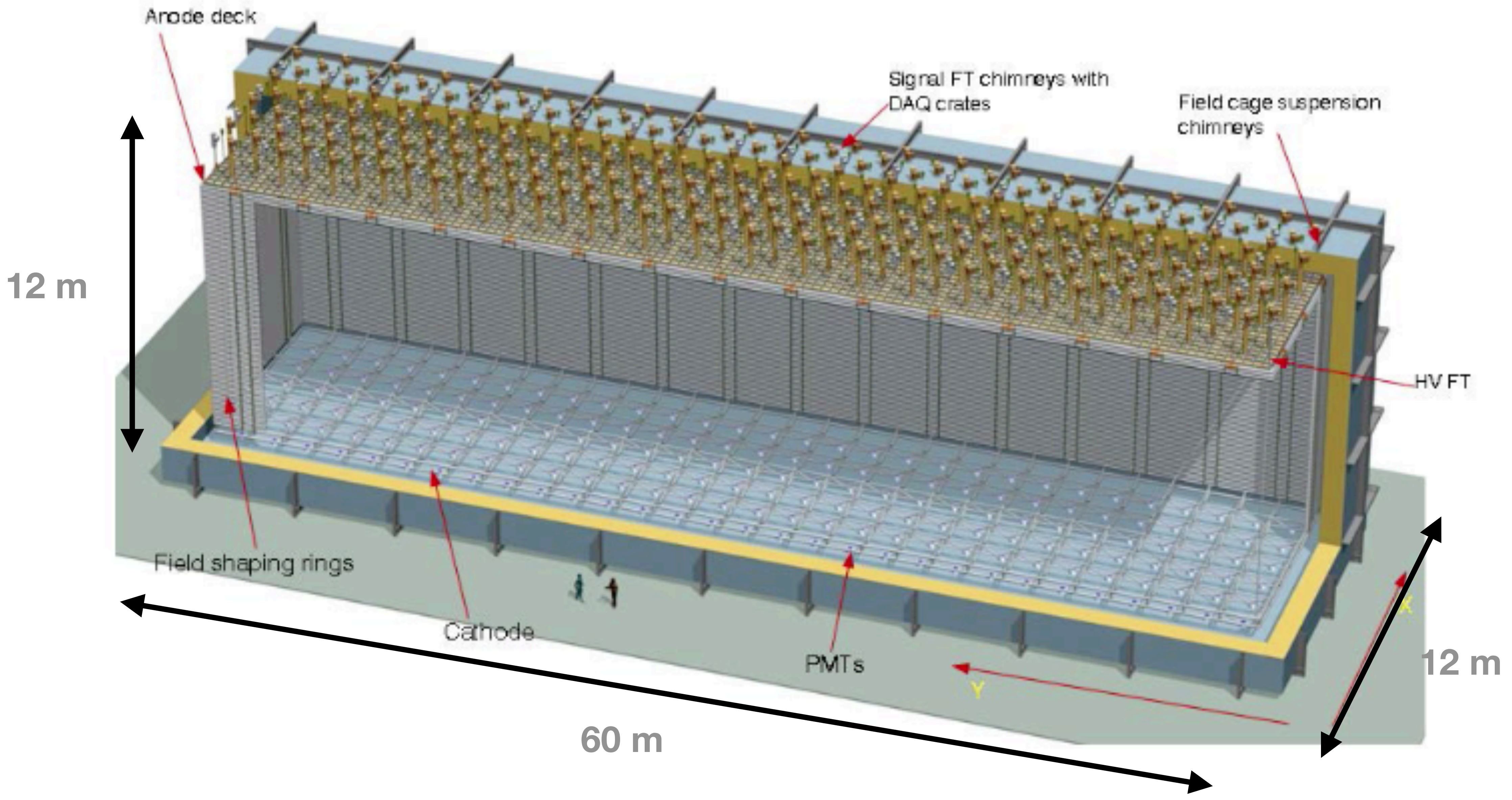


The DUNE Far Detector.

Dual Phase technology

- Differences with SP technology
  - ➠ Adding **amplification** of the drift electrons in a LAr gas phase
  - ➠ Allow for a for a single drift volume with **longer drift distance**
- Micro-pattern detector (**LEM**) ➠ amplify electrons in avalanches
- Avalanches are collected on the anode (CRP - **2D strips**)
- Advantages compared to SP
  - **Higher S/N**
  - Larger active volume (*less dead material*)
  - **Finer** readout pitch, less channels
  - Fewer modules/Access to the FE electronics
- ➠ ***Maximises the capabilities of the DUNE experiment***

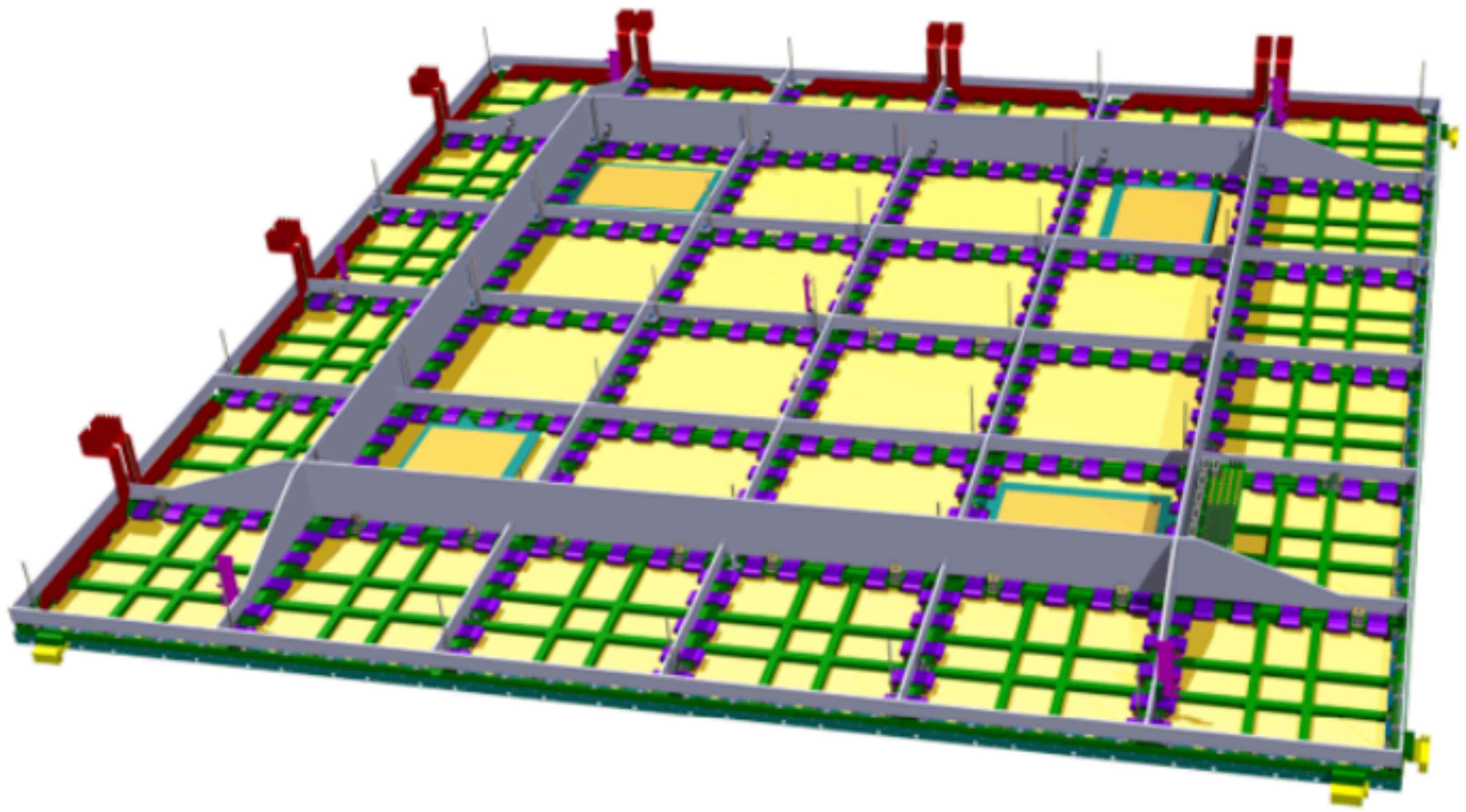




The DUNE Far Detector.

Dual Phase technology (Anode - CRP/LEM)

Full CPR design



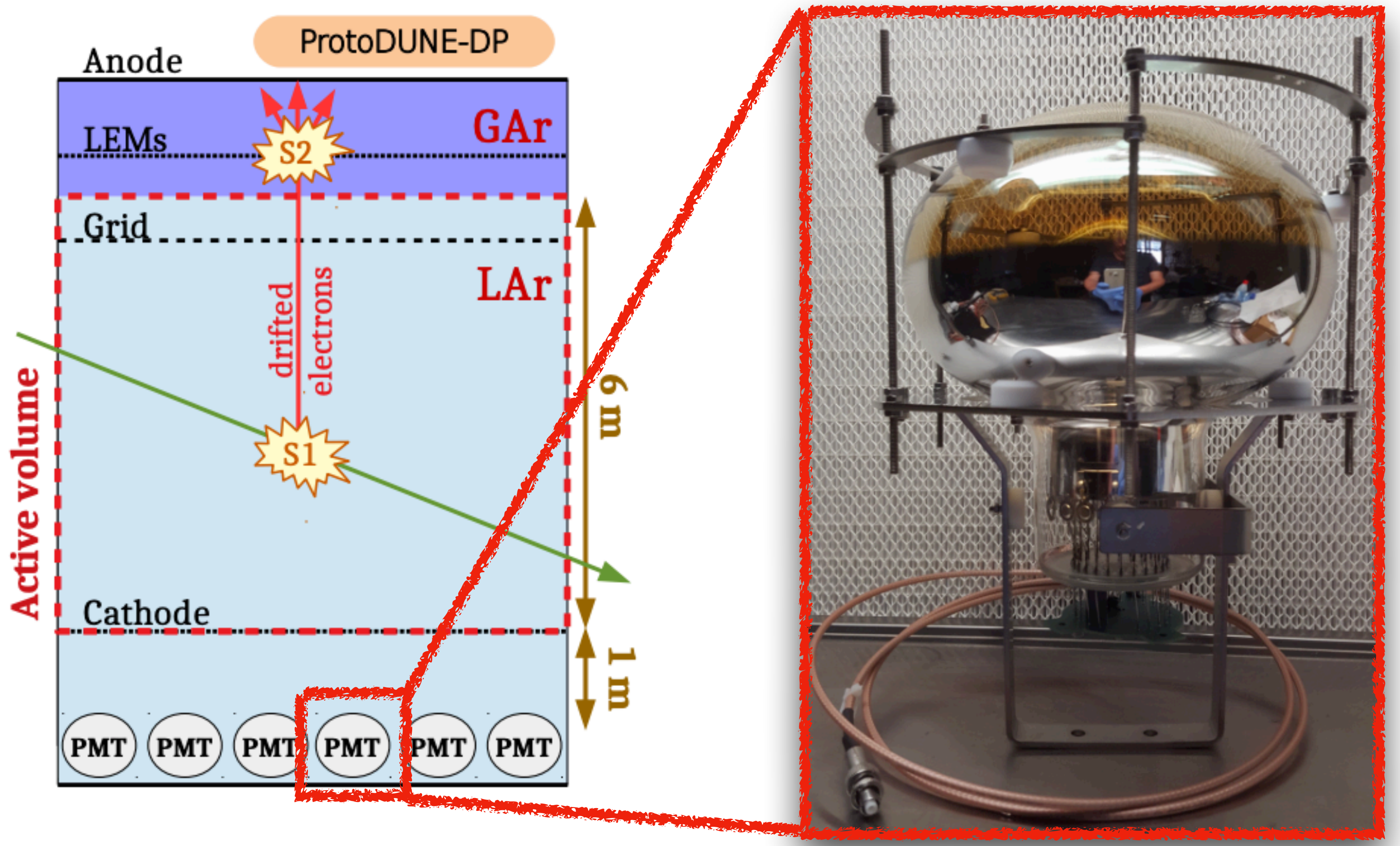
- A full CPR module is 9 m² (Anode + Frame + LEM)
- Number of CRP in a FD module: 80 (4 x 20)
  - ➠ **~153k channels**
- LEMs
  - 1mm thickness, area 50x50 cm², copper-clad PCB plate
  - Micro-pattern gas detector: ~500 µm diameter (800 µm pitch) ➠ 180 holes/cm²
  - Outer guard ring: 10 mm free of metallisation, 5 mm copper guard ring
  - **Active area ~ 86%**, 3.5 kV design operation (> 30 amplification gain)
- Anode
  - Same area as LEM
  - Copper strips for 2D position (**~3 mm pitch**)
- Critical: careful alignment and positioning (2 mm distance) between anode and LEM ➠ 26 machined spacers

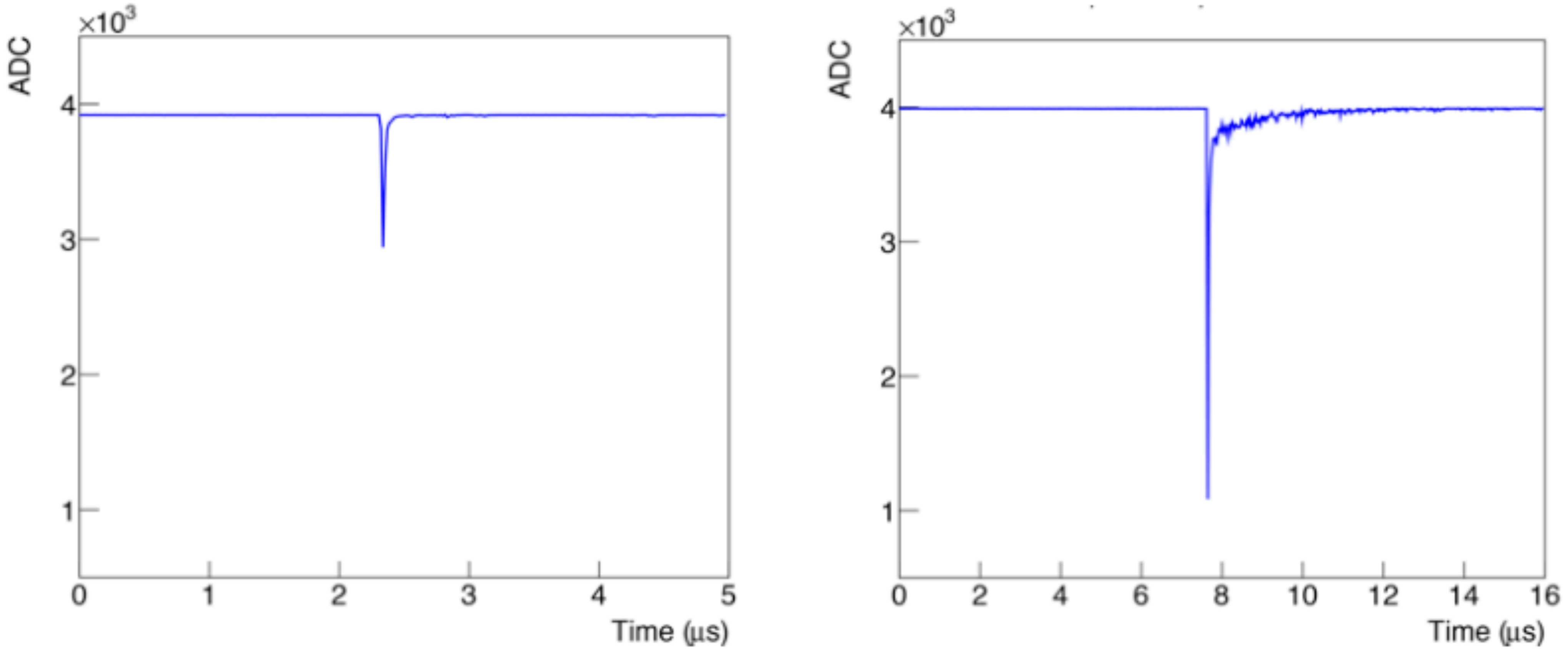
LEM

The DUNE Far Detector.

Dual Phase technology (PD system)

- Similarly as in the SP: light is produced along ionisation (127 nm)
- For the DP: two signals prompt (**S1**) and delayed (**S2**)
  - Give **time** of the event (S1)
  - Give **measurement** of ionisation charge (S2)
  - Give **drift time** (S2-S1)
- 8 inch PMTs from different manufacturers: Hamamatsu, ELT (US/UK), HZC (China)
  - Baseline: *Hamamatsu R5912- MOD20*
- PMTs are coated with TBP to shift the light to ~430 nm
- Designed for high gain (**10^6-10^9**), cryogenics and resists 2 bar pressure, **ns** time resolution
- Number of PD in a full module (PMTs): **720**
- Electronics
  - Advance Mezzanine Cards (AMC): 64 channels, 12 bits, ~2.5 MHz sampling frequency
    - Based on the CATIROC ASIC
  - Optical link backend at **10 Gbps**



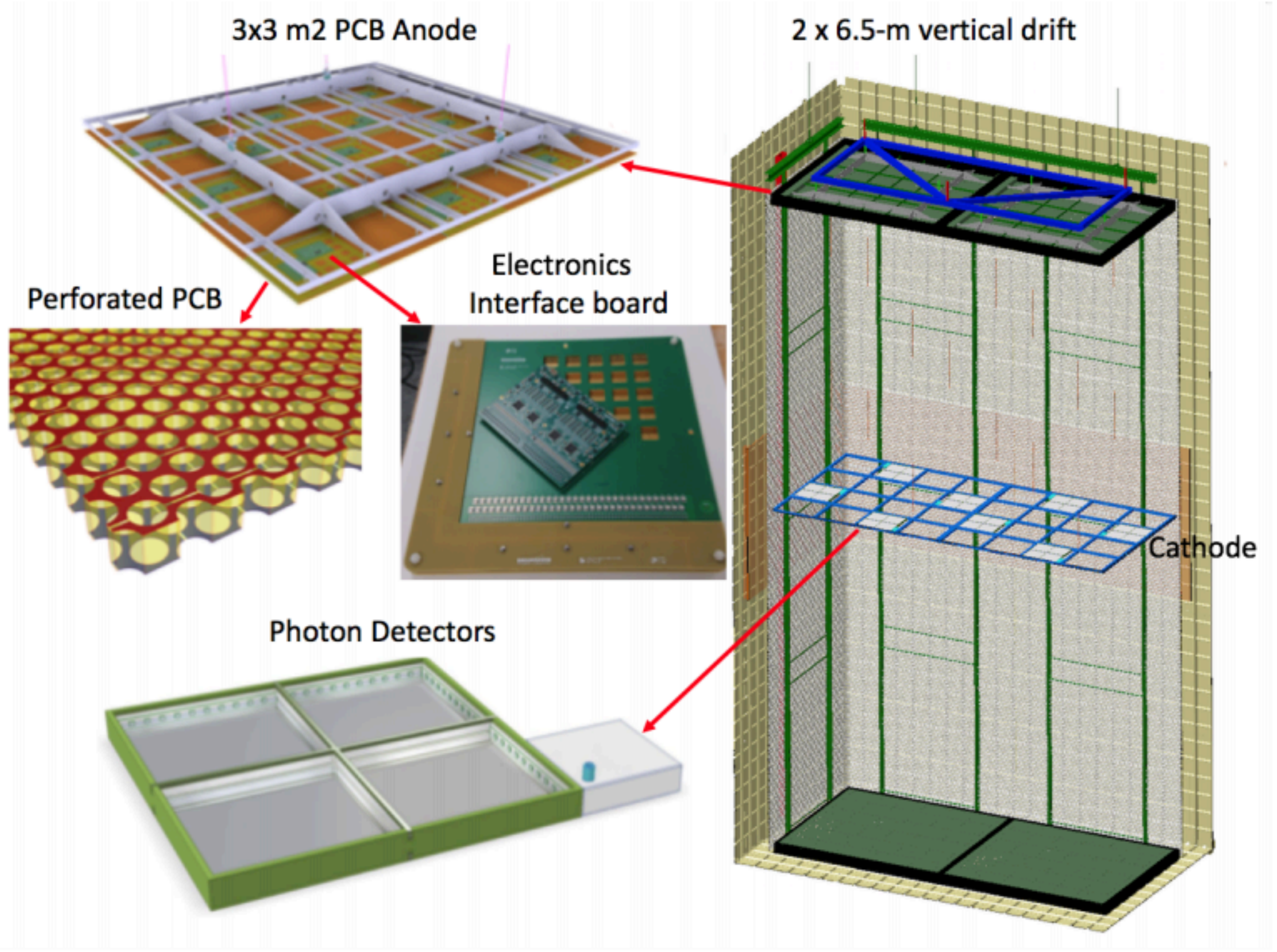


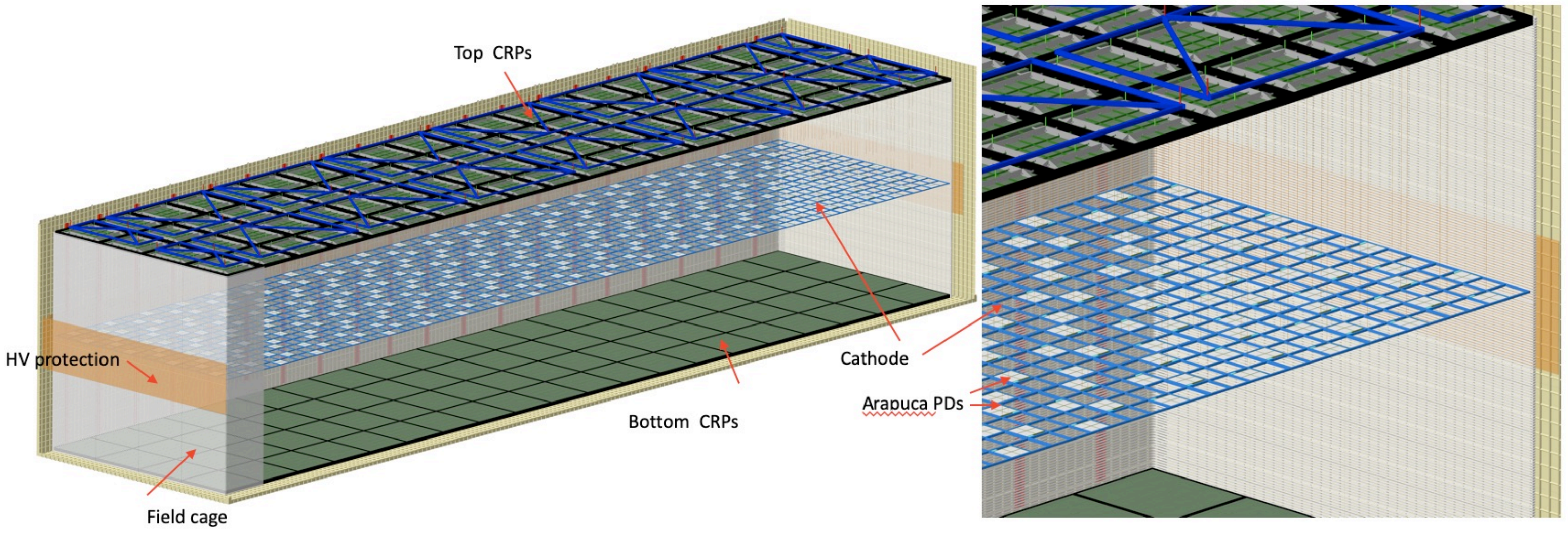
ProtoDUNE DP PMT signal in GAr/LAr

The DUNE Far Detector.

Issues with Dual Phase technology

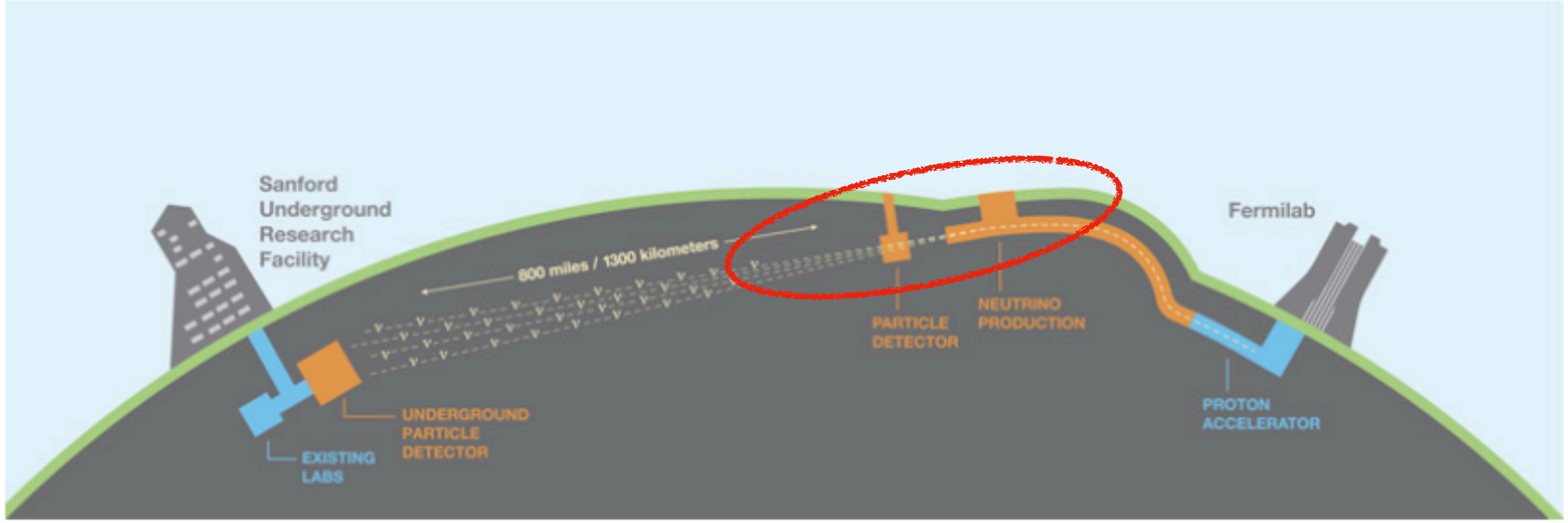
- DP is a very interesting concept but it has a few issues
  - It provides 2 views ➠ difficulties in “classic” reconstruction
  - Operation a very high voltages (600 kV) + HV in gas phase
  - Electron lifetime is good enough (> 10s ms) to mitigate the gains with DP
- ➠ New technology being developed: **Vertical Drift** concept
- Best of both worlds: combine advantages of SP/DP technologies
  - Transparent cathode at middle height ➠ better HV stability
  - Readout planes at LAr surface and cryostat floor using perforated anodes with segmented strips (3 views possible) and integrated readout electronics ➠ better modularity and stability
  - PD integrated inside the cathode ➠ better integration and HV decoupling with fibers for power/data





Contents of this talk.

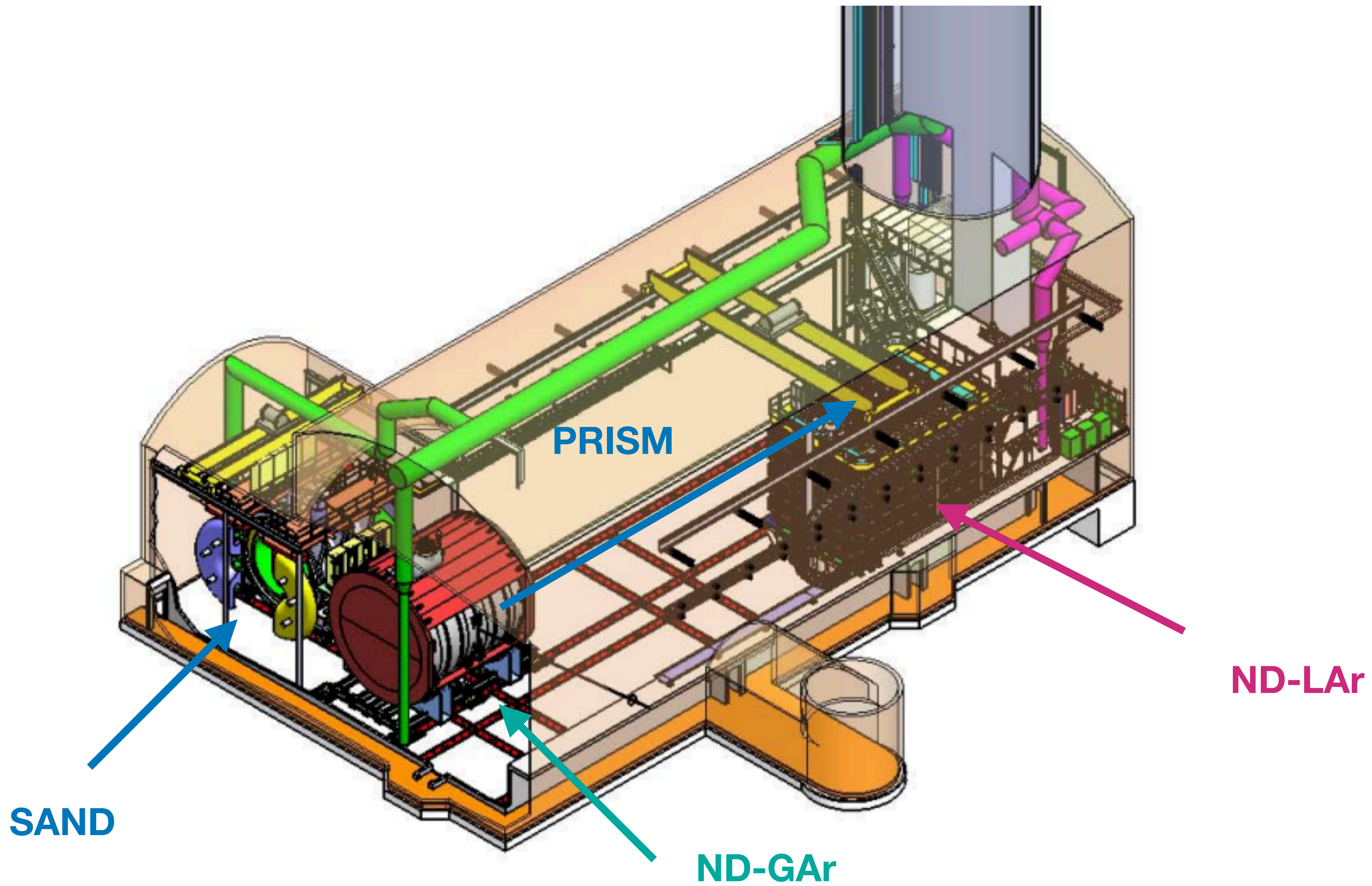
- The neutrino mystery
- The Deep Underground Neutrino Experiment
- The physics goals of DUNE
- Pushing the limits in terms of technology
  - The Far Detector
  - The Near Detector
- Summary

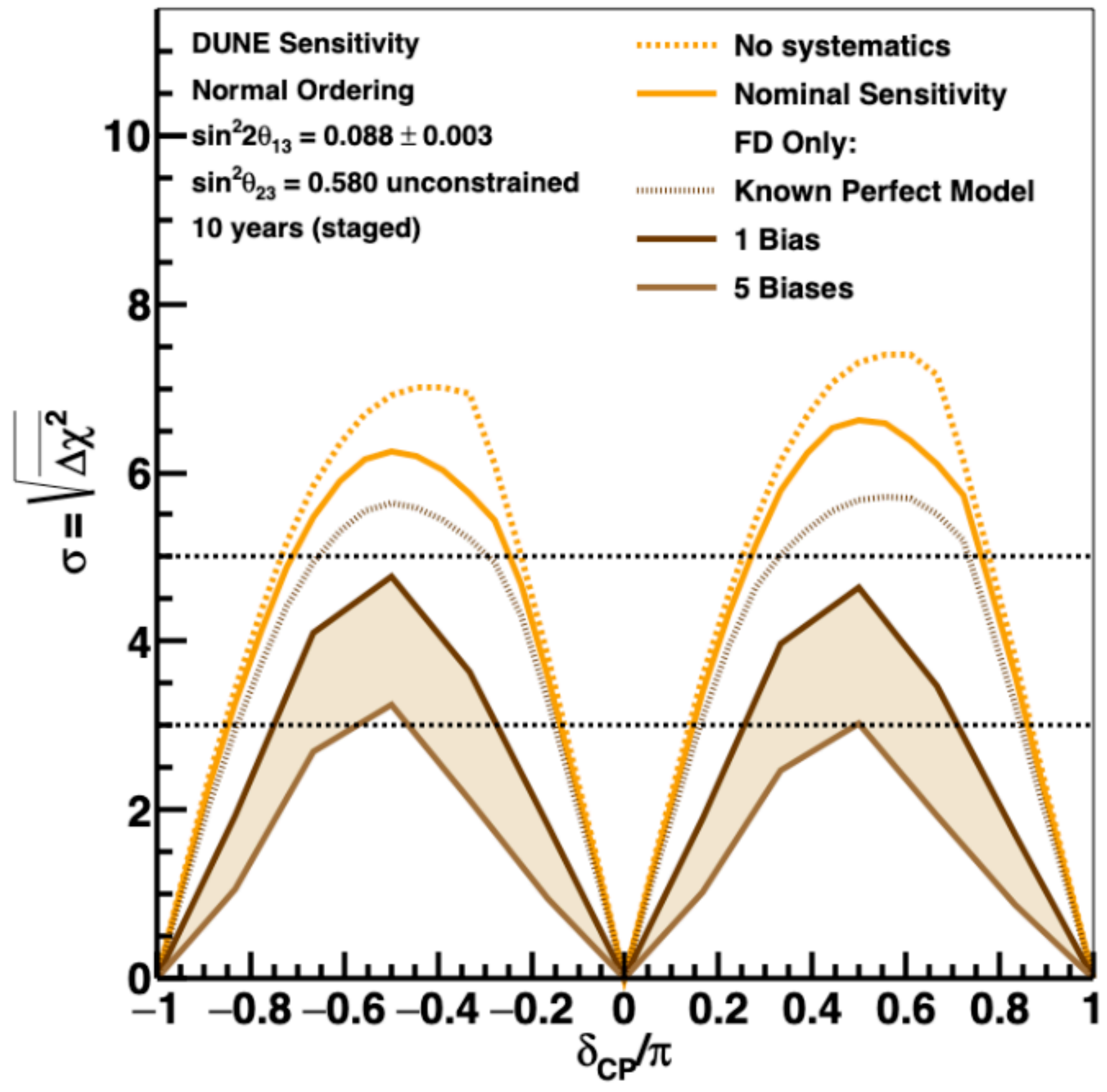


The DUNE Near Detector Complex.

Overview

- Near Detector Hall situated at Fermilab
  - ~580 m from beam target
  - 60 m underground
- House various ND detector components
  - A modular LArTPC (**ND-LAr**)
  - A high-performance GArTPC (**ND-GAr**)
  - A beam monitoring detector (**SAND**)
- Enables the **DUNE PRISM** concept
  - ND-LAr/ND-GAr can move off-axis (change in flux and spectrum of the neutrino beam) ➠ provides measurements needed for oscillation parameter measurement without a priori knowledge of ν-Ar cross sections and event energy reconstruction
- Physics Goals
  - Extrapolate **neutrino flux** to the FD
  - **Constrain uncertainties** in extrapolation, cross-section measurements, neutrino flux and neutrino energy spectrum
  - ➠ **Enables large standalone physics program provided by the various detector technologies**

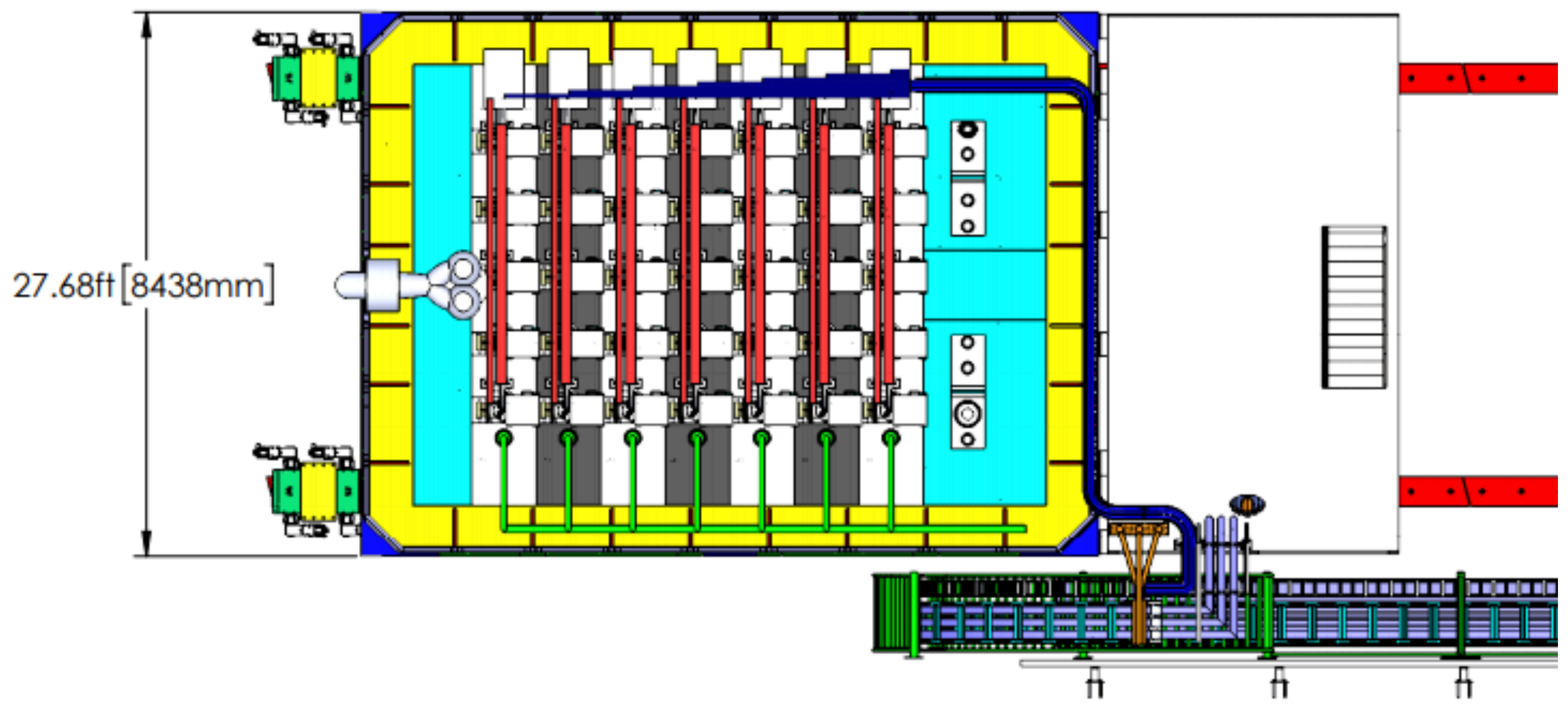


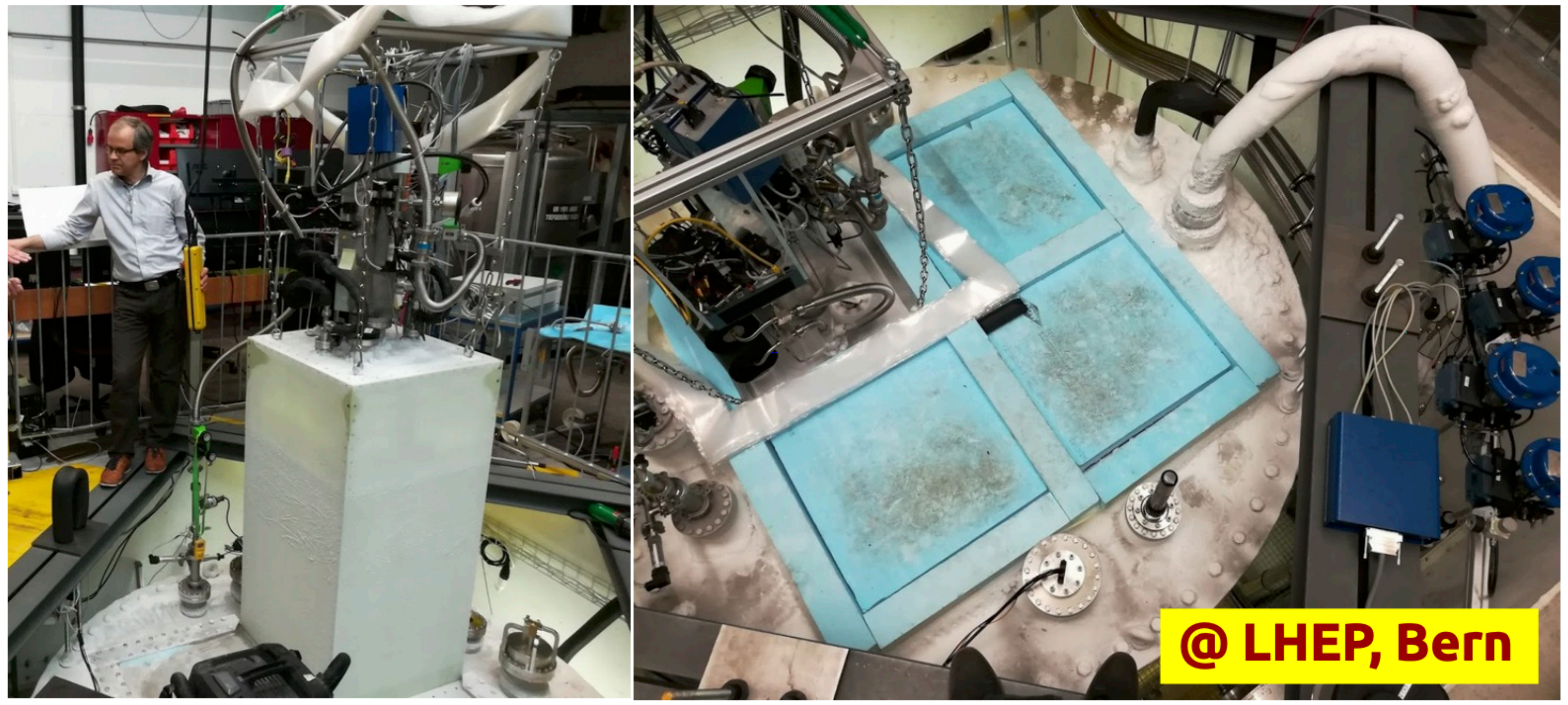


The DUNE Near Detector: ND-LAr.

A Highly modular LArTPC detector

- Same target material as the FD: **50t FM**
- Needs to be suitable for a high-rate environment (**~50 events per spill**)
  - Use **pixelated charge readout** instead of wires
  - **Modularisation** ➠ allows for lower drift distance and times, less problems with overlapping interactions
  - Provide **precise timing** of the event ➠ advanced photo-detection system
  - Best active area ➠ unique design of the modules to minimise dead space and power release (breakdown)
- Key designs:
  - Size (w/ cryostat): ~11x8x5 m (L/W/H)
  - 35 optically separated modules (FC+TPC+PDS)
  - Cryostat based on ProtoDUNE design
- Demonstrator already built at BERN
- 2x2 Demonstrator planned at Fermilab



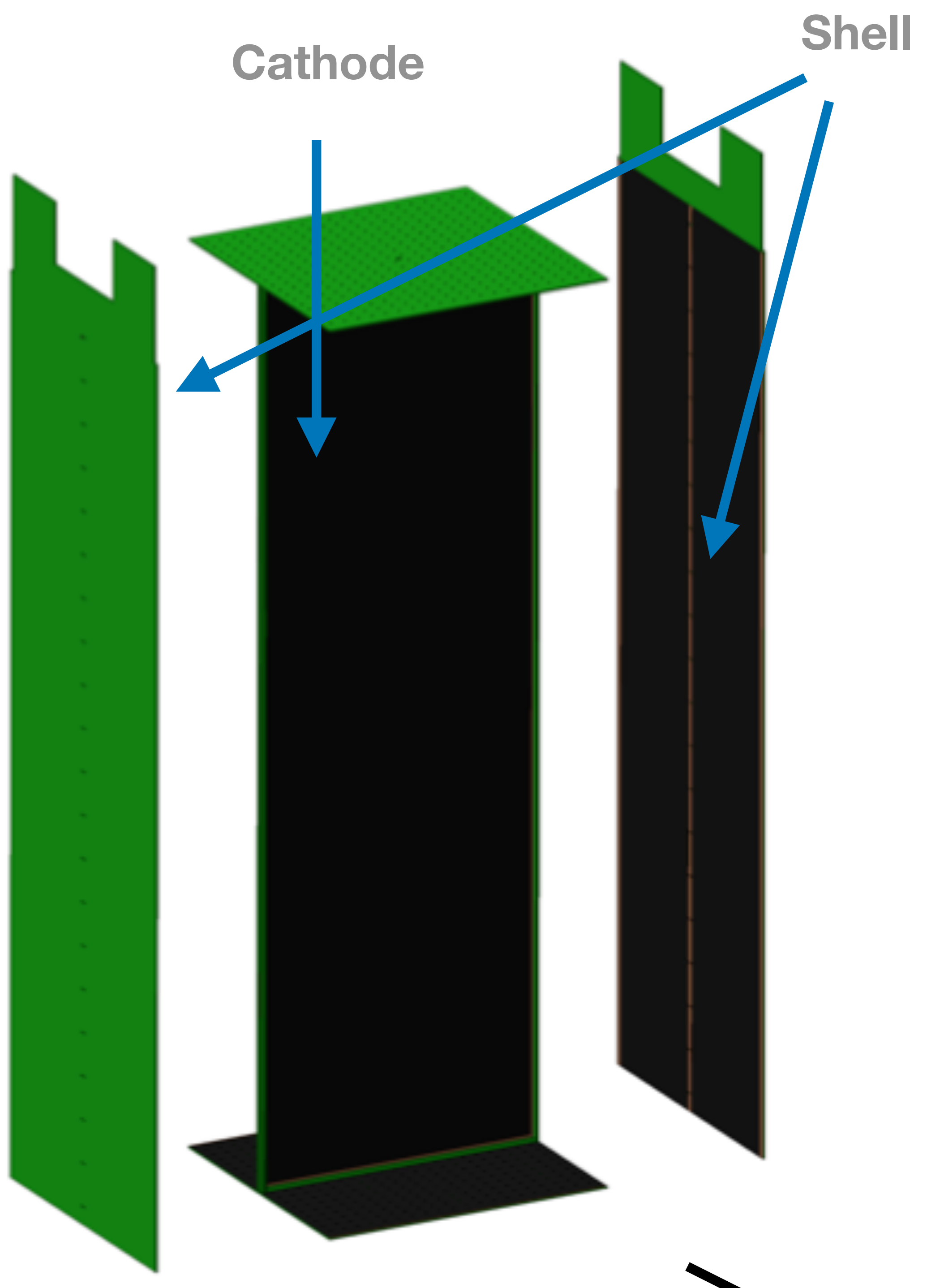


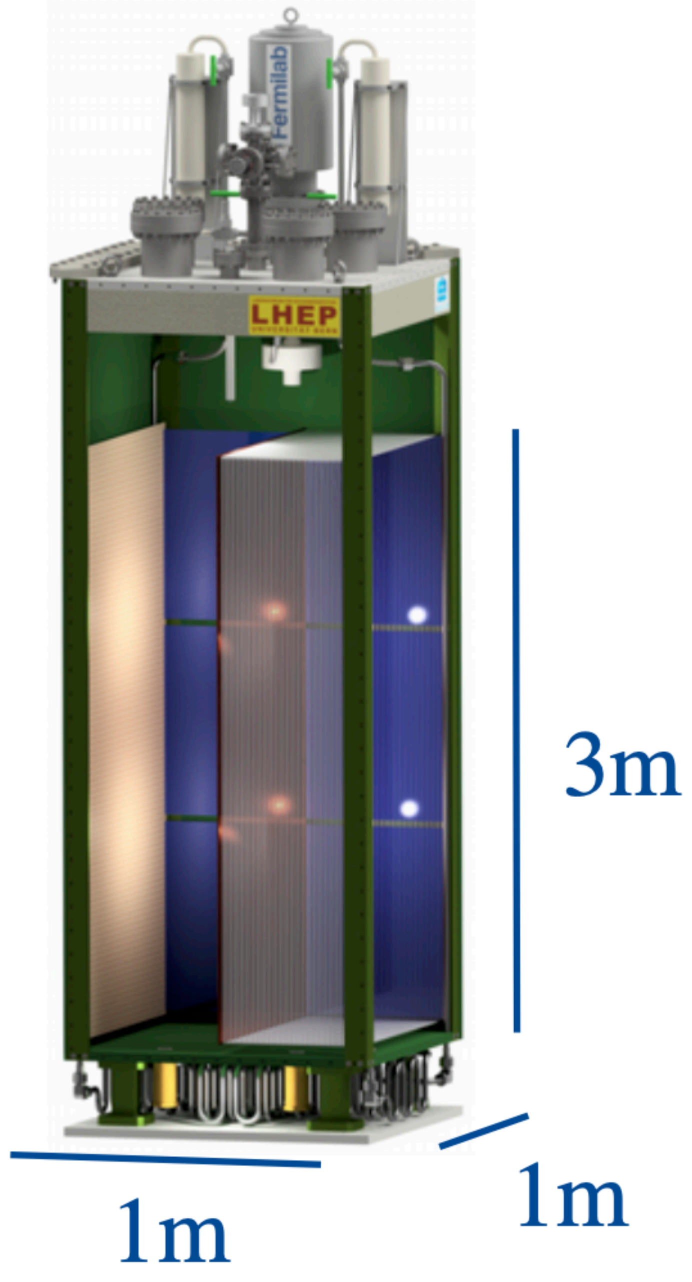
ND-LAr demonstrator at BERN

The DUNE Near Detector: ND-LAr.

A Highly modular LArTPC detector (TPC system)

- Same requirements as the FD
    - <1% field uniformity
    - Stable under 250 V/cm (up to 500 V/cm)
    - Low heat dissipation (<100 mW/cm2)
- Module size: 1x1x3.5 m (W/L/H)
- Field Cage Structure
    - 5 copper-clad, 6 mm thick FR4 panel covered in Kapton (resistive)
- Advantages
    - Small footprint (maximises active area)
    - Minimised resistive heating (spread over the full surface of the cage)
    - Provides mechanical support for the module



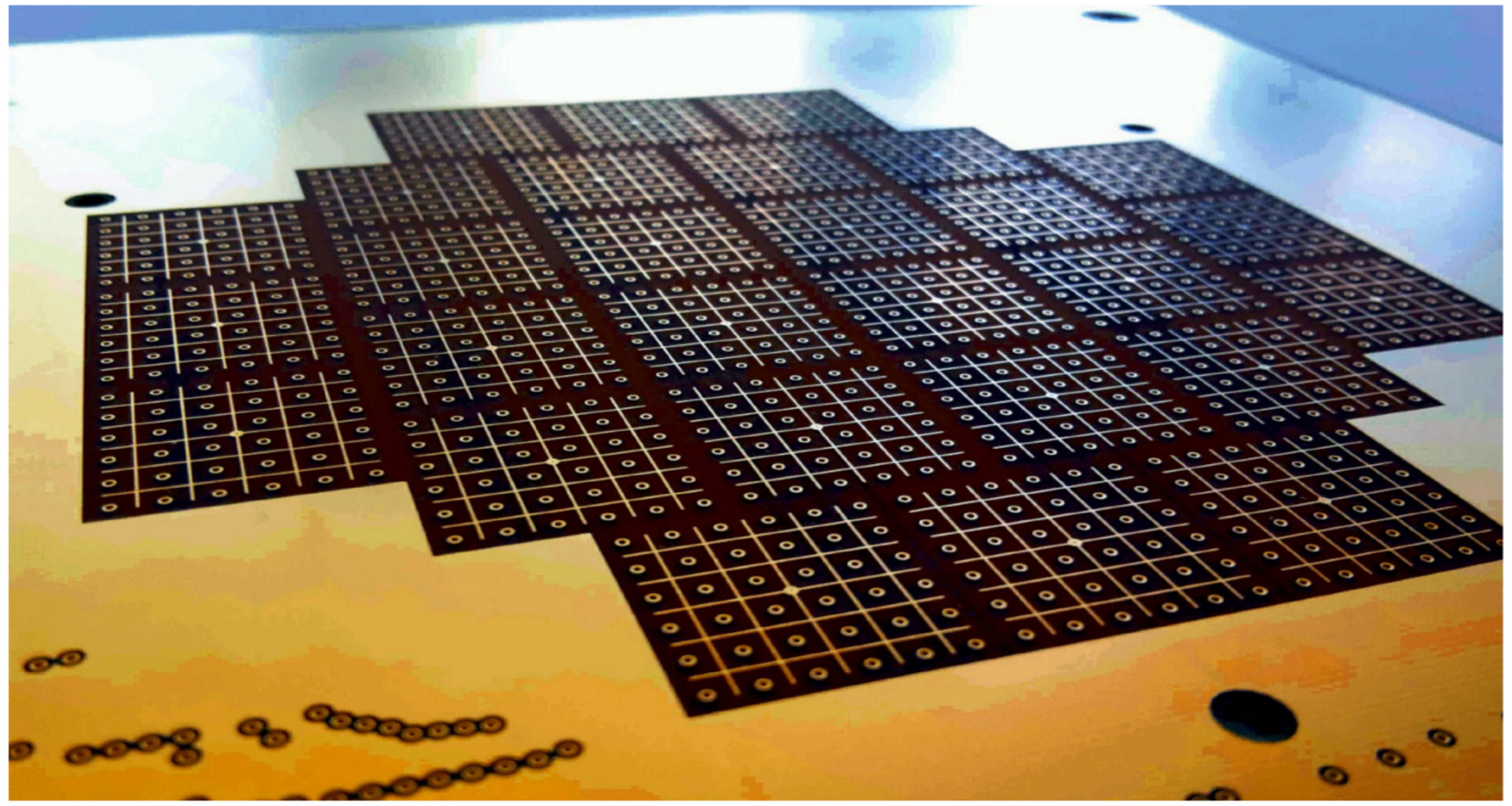


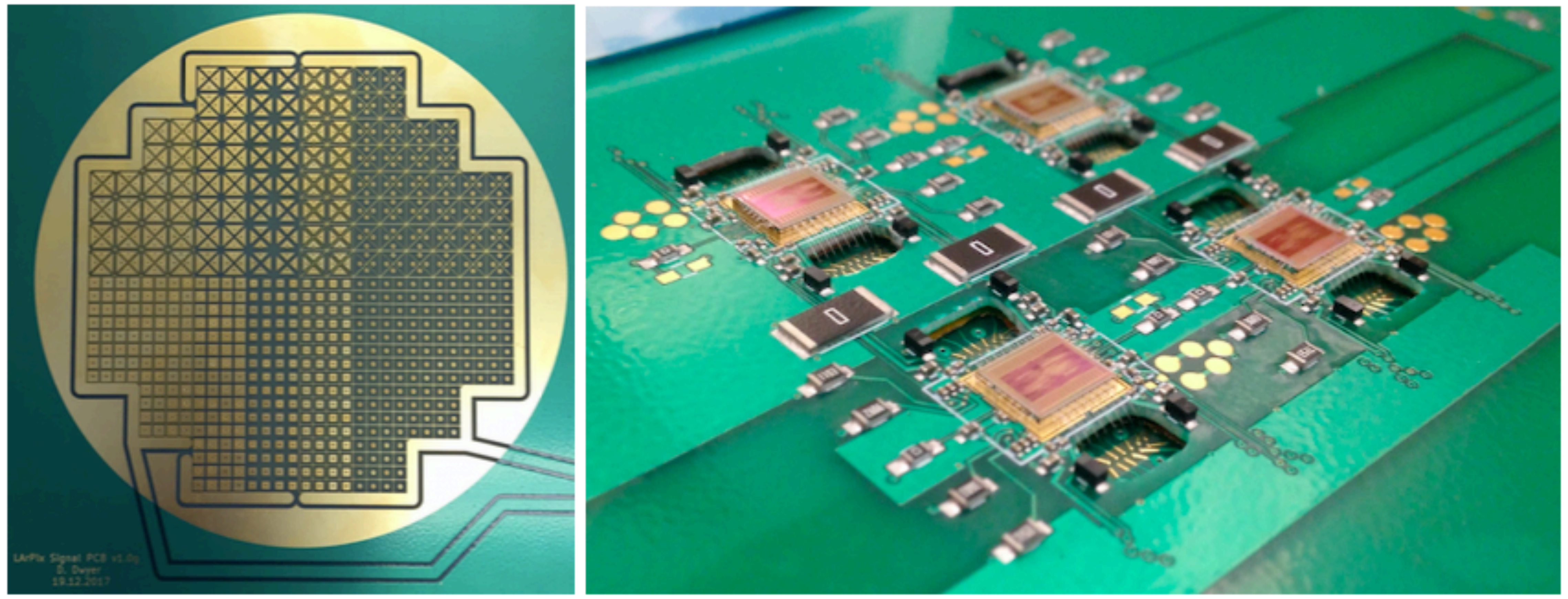
Field Cage prototype

The DUNE Near Detector: ND-LAr.

A Highly modular LArTPC detector (Pixel Readout)

- **State of the art** pixel readout
  - First of *its kind in LArTPC*
- Anode
  - Total surface: **200 m^2** of pixelated anode
  - Pixel size: 4x4 mm^2
  - Full anode, organised in 20 tiles in two columns ~10k channels per tiles
    - 70 anodes in total ~ **700k channels!**
    - Compromise between space resolution, channel density, heat load
- Electronics
  - **LArPix** ASIC: 64 channels, 6 bits ADC, 5 MHz clock
    - Self triggering chip, zero-suppression
    - Serial protocol to send out the data (holds up to 2048 records) - Data rate: **5 Mb/s** (@5 MHz)





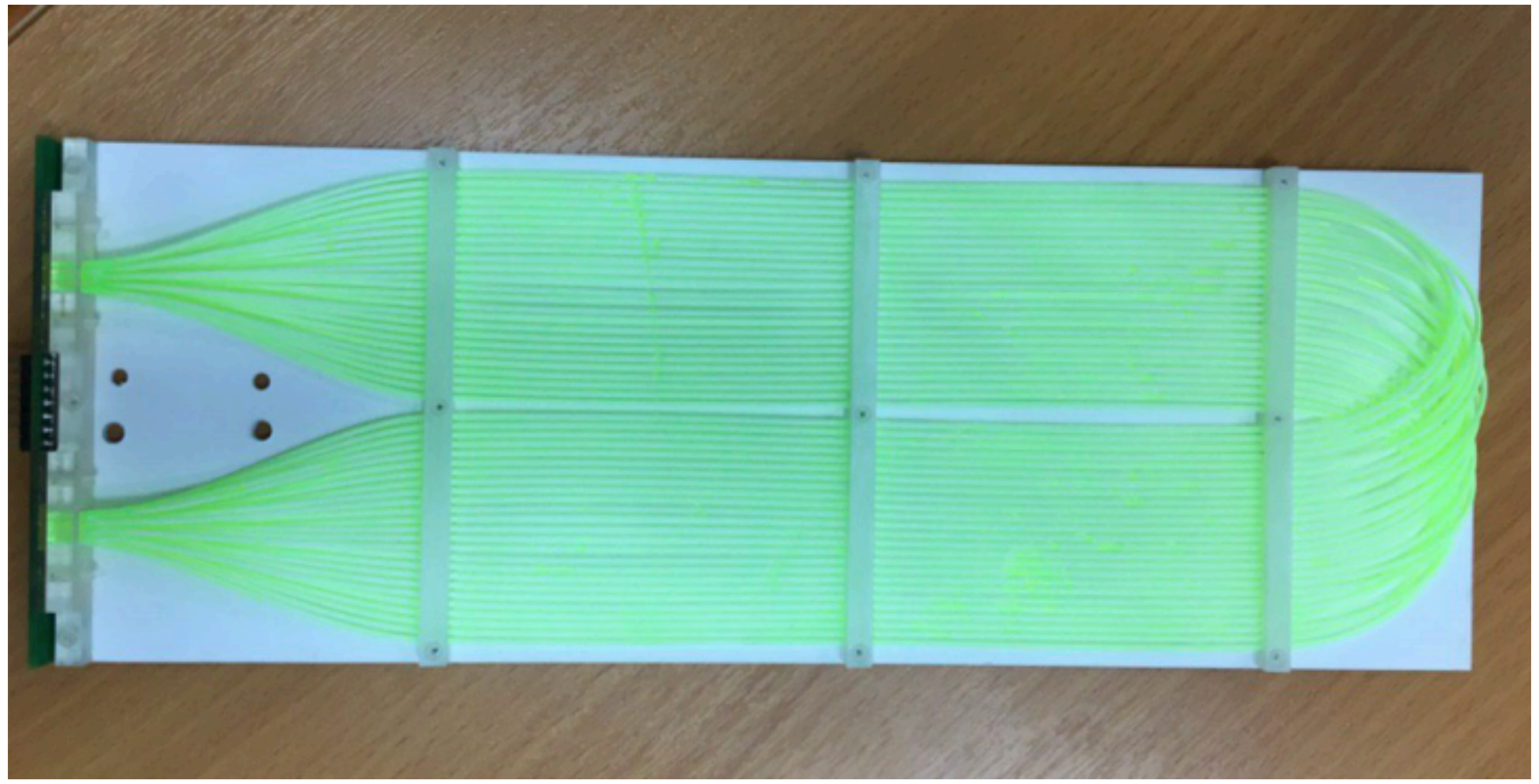
LArPix on the back of the anode PCB

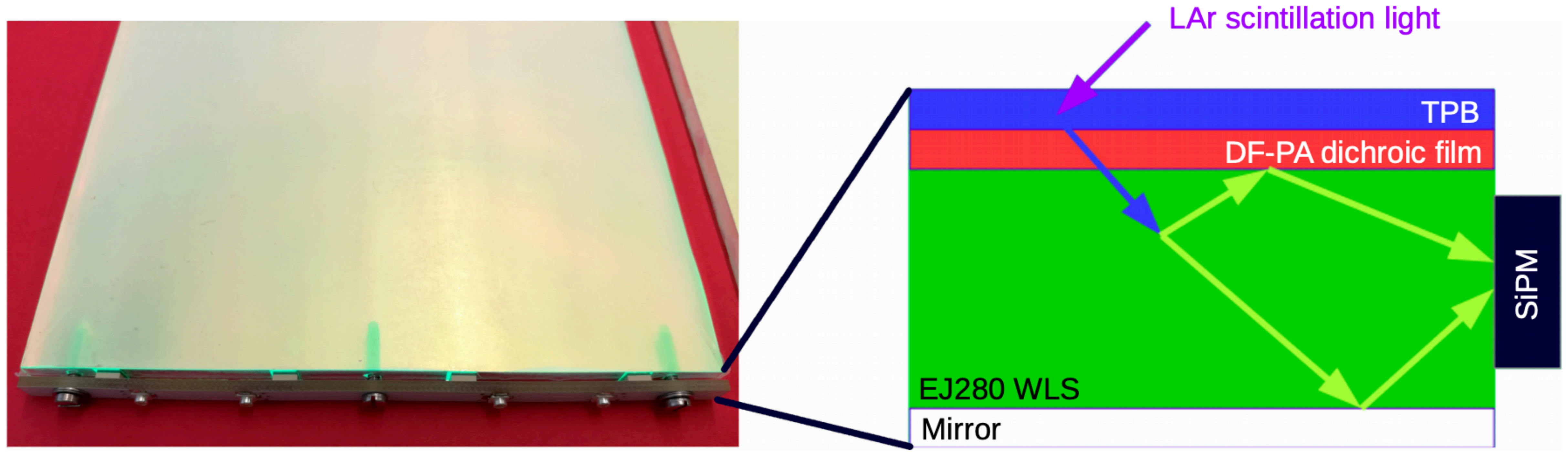
The DUNE Near Detector: ND-LAr.

A Highly modular LArTPC detector (Light System)

- Two designs: Light Collection modules (**LCM**) and **ArCLight**
- 60 LCM and 20 ArCLight detectors per module
- Tightly integrated in the LArTPC module
  - Better light yield (dielectric)
- **LCM**
  - Uses wavelength shifting fibres along a module side bend into 2 bundles
  - Fibers are optically coupled to a SiPM
- **ArCLight**
  - Uses the *ARAPUCA* device
  - Sheets of WLS plastic coated in TPB and dichromic mirrors
  - Readout by 3 SiPMs
- LCM has better **efficiency** while ArCLight has a better **position** resolution

LCM



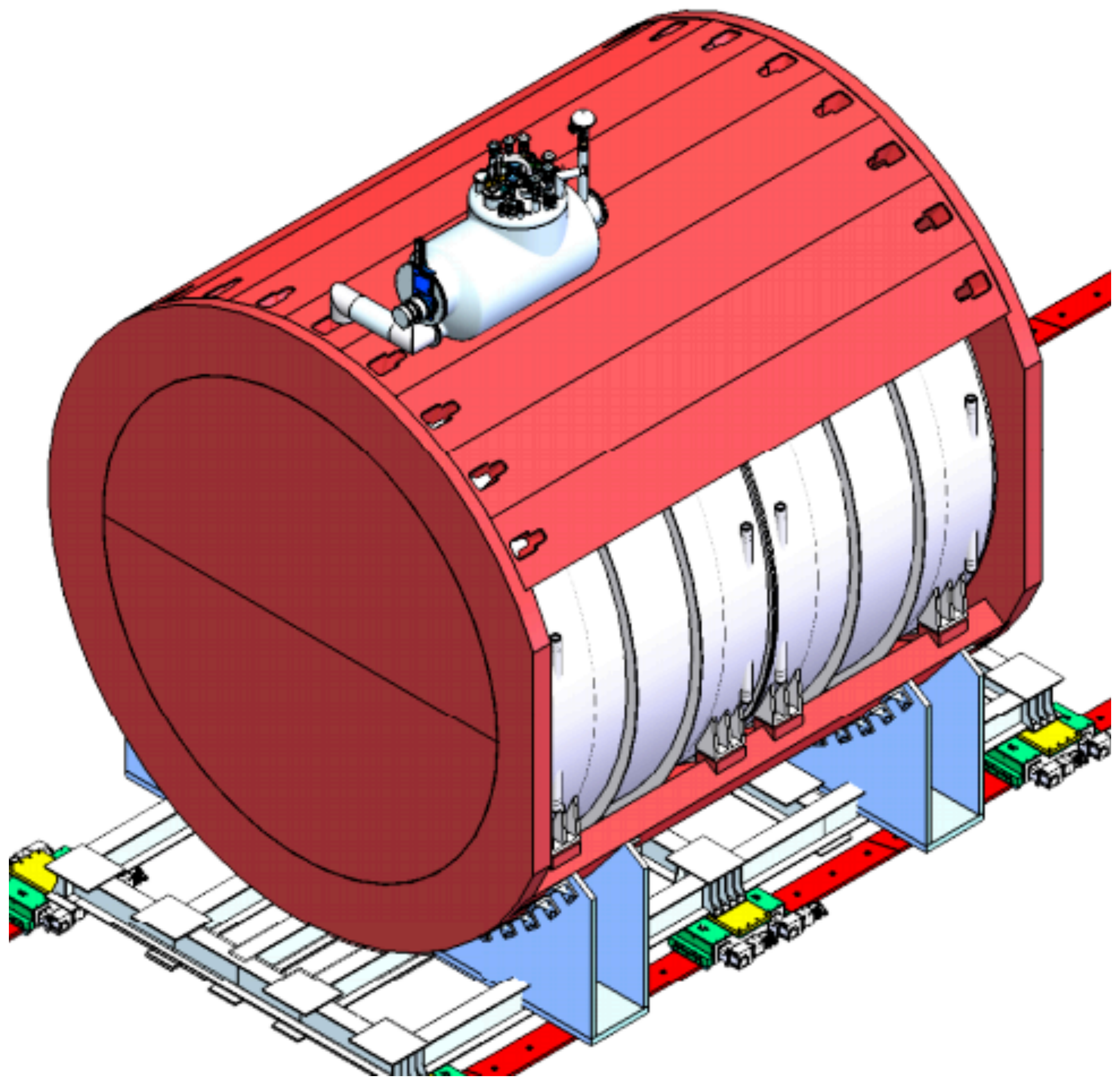


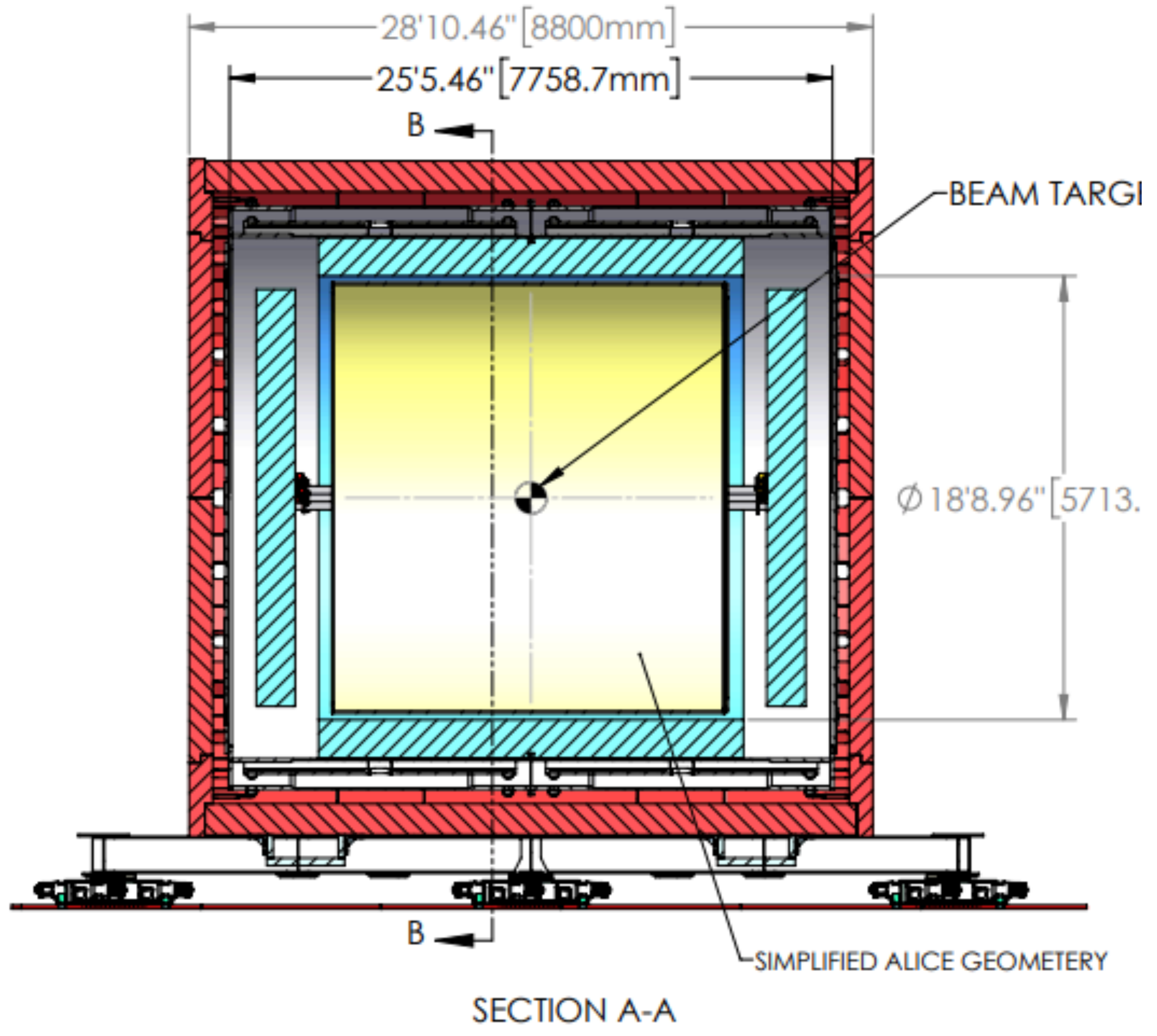
ArCLight

The DUNE Near Detector: ND-GAr.

A high performance gas detector

- Placed behind the ND-LAr
  - Acting as a **spectrometer** for particles exiting the ND-LAr
  - Provides its **own physics program** for ν interactions on gas argon
- Key components
  - High Pressure (**10 bar**) GArTPC as tracker
  - Surrounded by a **high performance calorimeter**
  - Inside a superconducting magnet and partial return Yoke (0.5 T)
- **Challenges**
  - Calorimeter integration inside the pressure vessel (PV)
  - Cryostat and Yoke act as the PV
  - Minimise fringe field and material budget

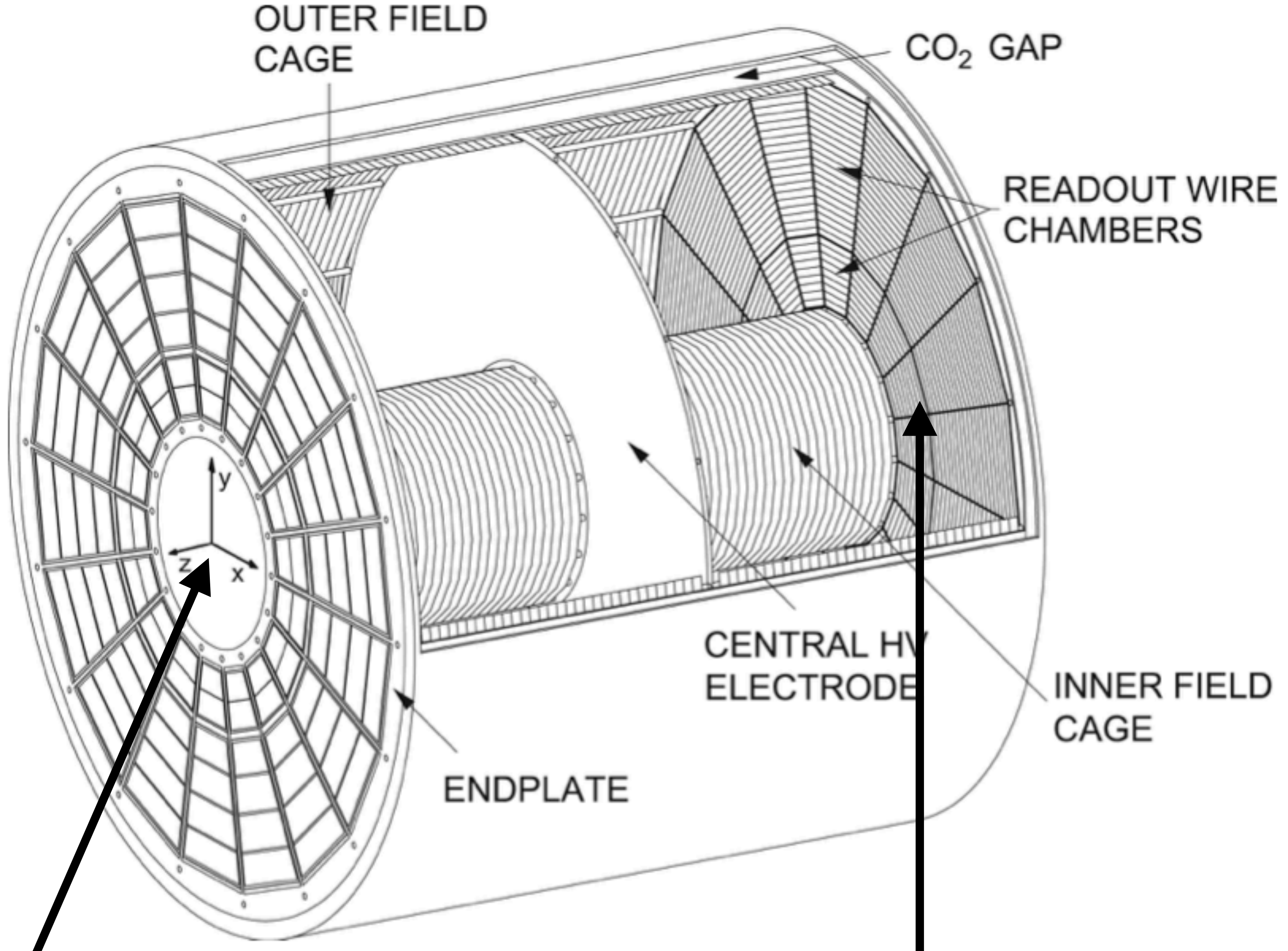


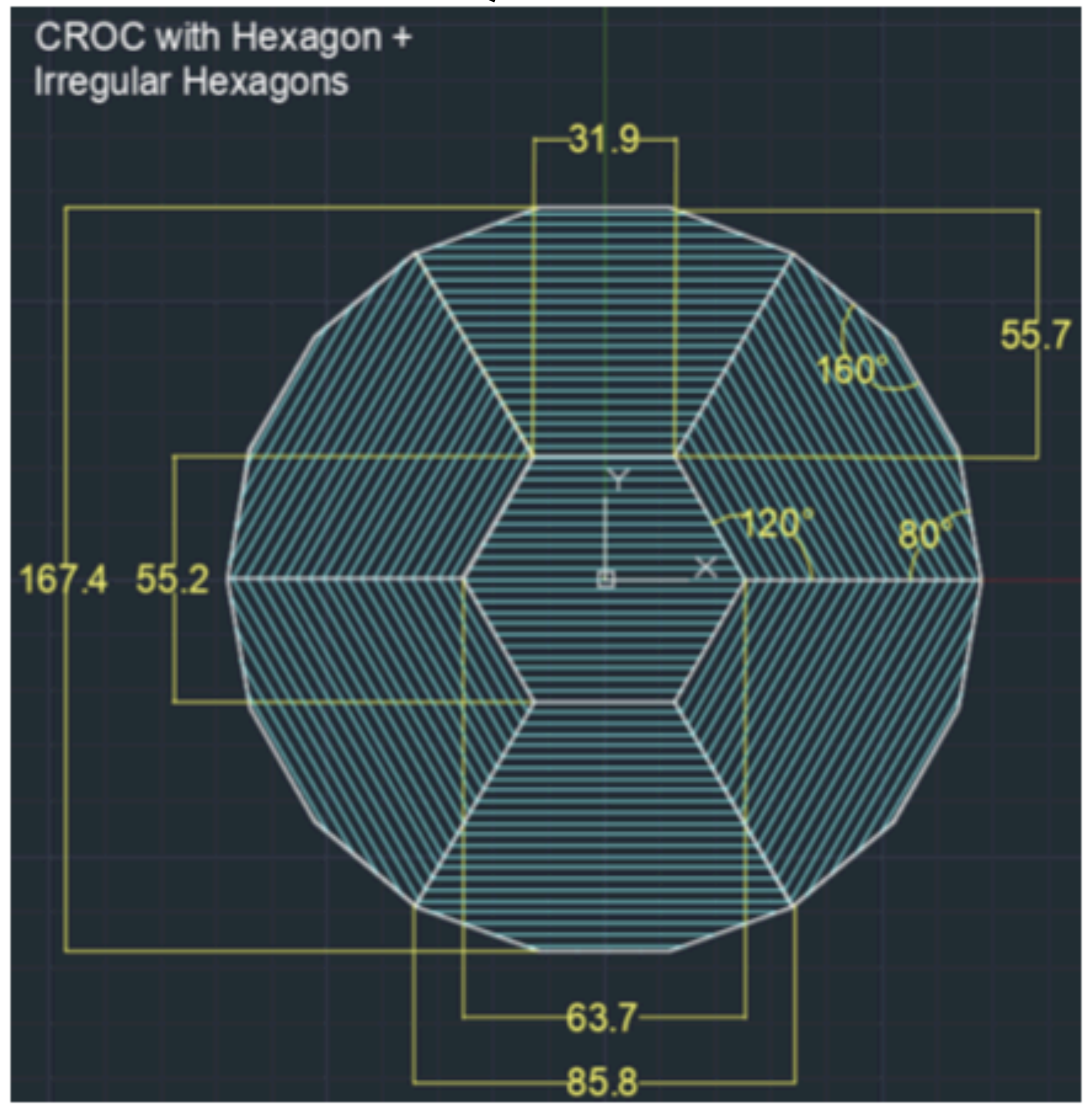


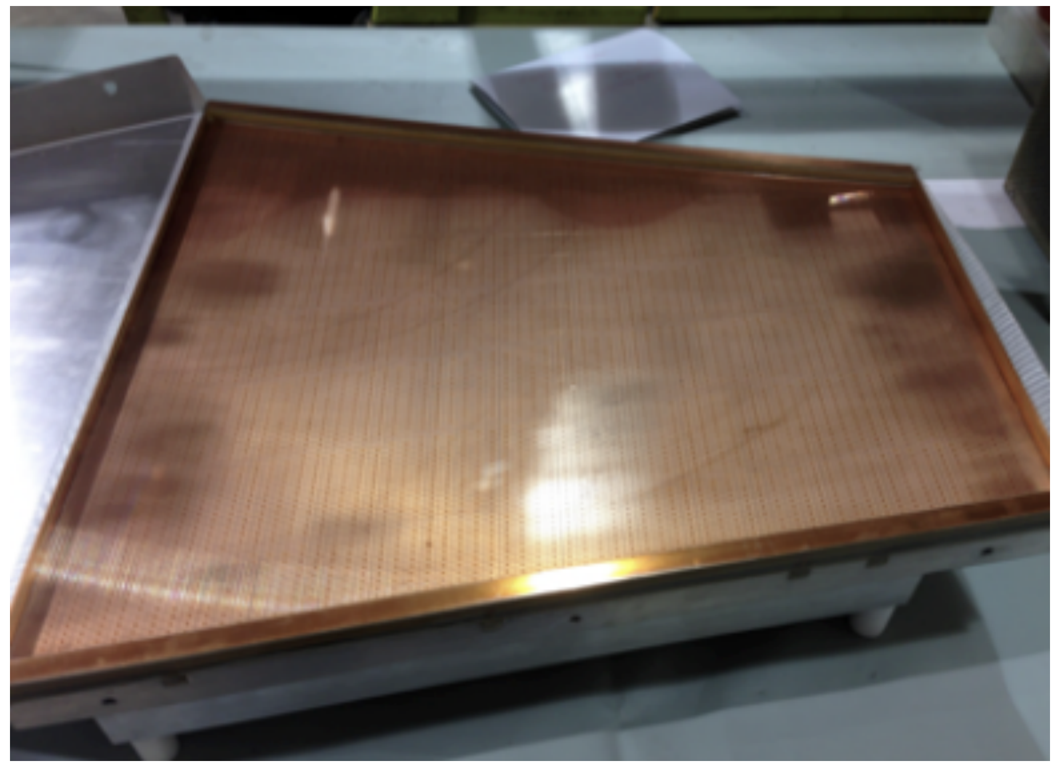
The DUNE Near Detector: ND-GAr.

A high performance gas detector (TPC)

- Design based on the **ALICE TPC**
- Gas Mixture: *Ar-CH4* (90/10%)
  - Being optimised for better drift velocity, quenching and transverse diffusion, breakdown voltage, gain…
- Two drift volumes of **2.5 m**
  - Middle anode using 25 μm aluminised Mylar
  - Readout chambers
    - Readout chambers (**MWPC**) from ALICE (IROC/OROC) - Acquired in 2019
    - Inner **pixelized** ROC
- Readout electronics
  - Likely based on the **LArPix** (with few adaptations)
- Light system
  - Would provide a t_0 for the event ➠ impacted by the gas mixture used
  - ***Novel opportunity for R&D*** for HPgTPC



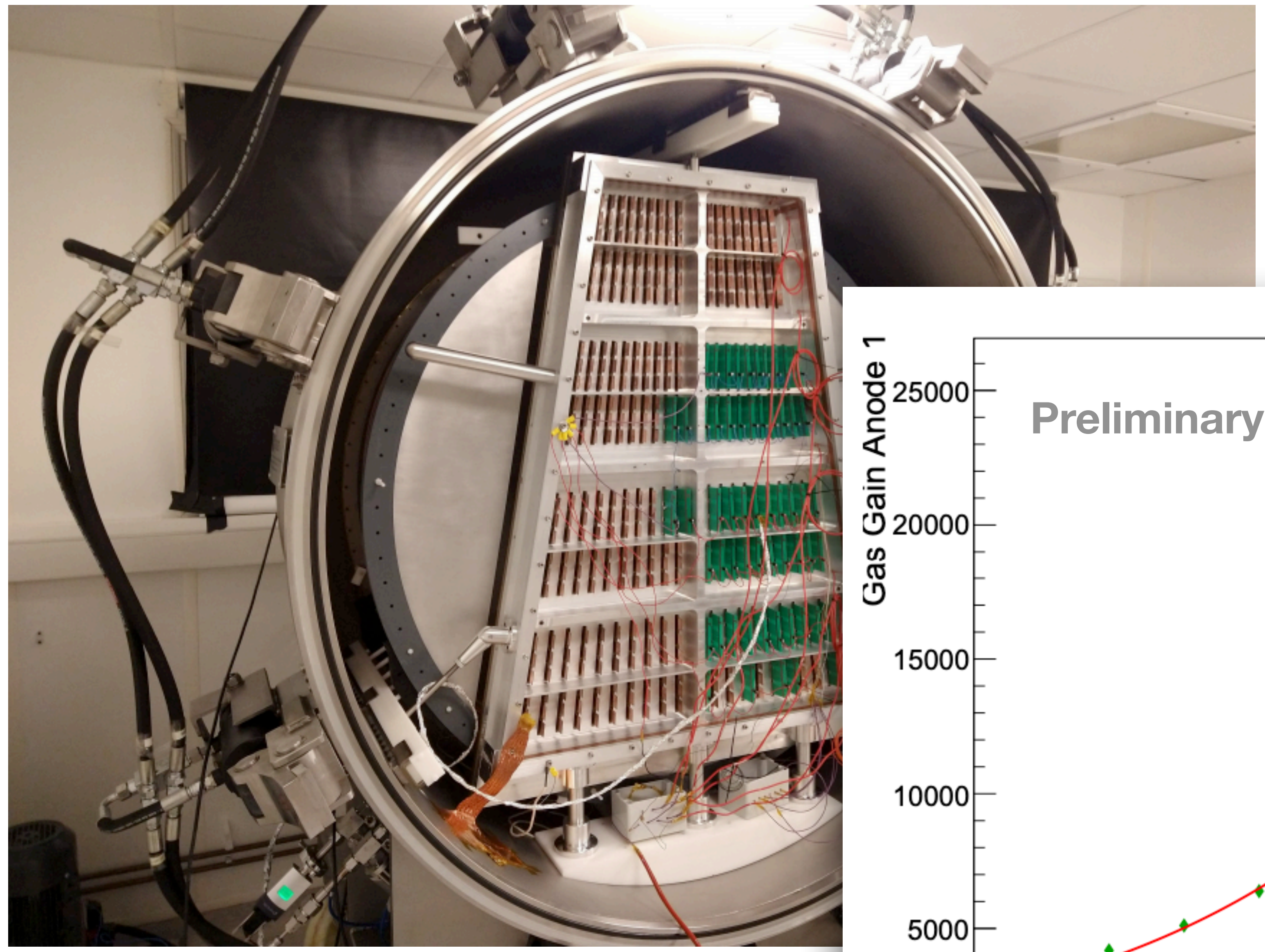




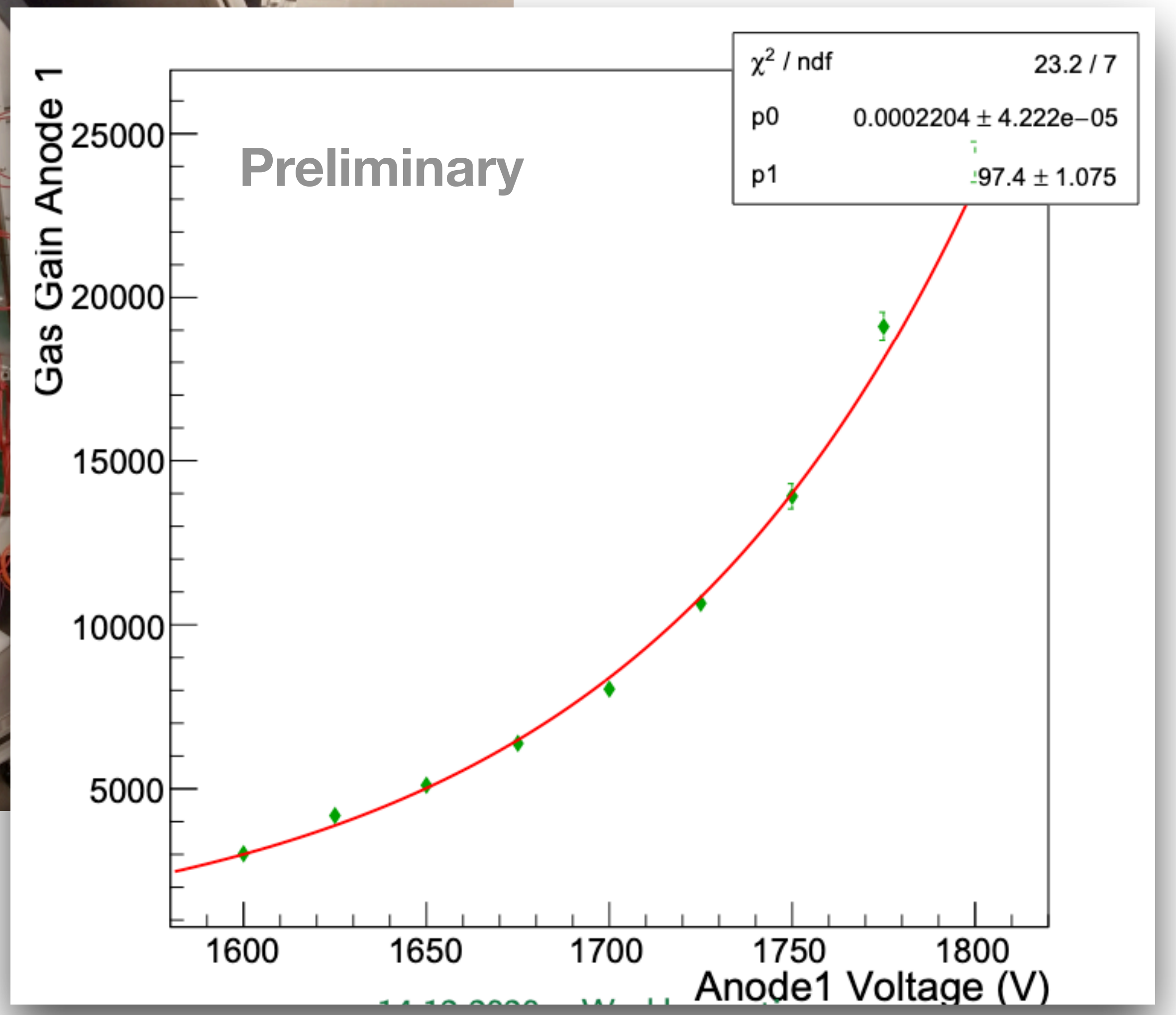
The DUNE Near Detector: ND-GAr.

A high performance gas detector (TPC)

- ALICE Chambers rated for 1 atm
- Need to be **tested** at 10 bar
  - ➠ Teststand at Fermilab (**GOAT**)
  - ➠ Teststand at **RHUL**
- Enables to test
  - Readout electronics
  - Different gas mixtures
  - Breakdown, gain as function of the gas pressure
- First tests performed at 1 atm
  - Test ongoing going up in pressure and voltage



OROC at RHUL

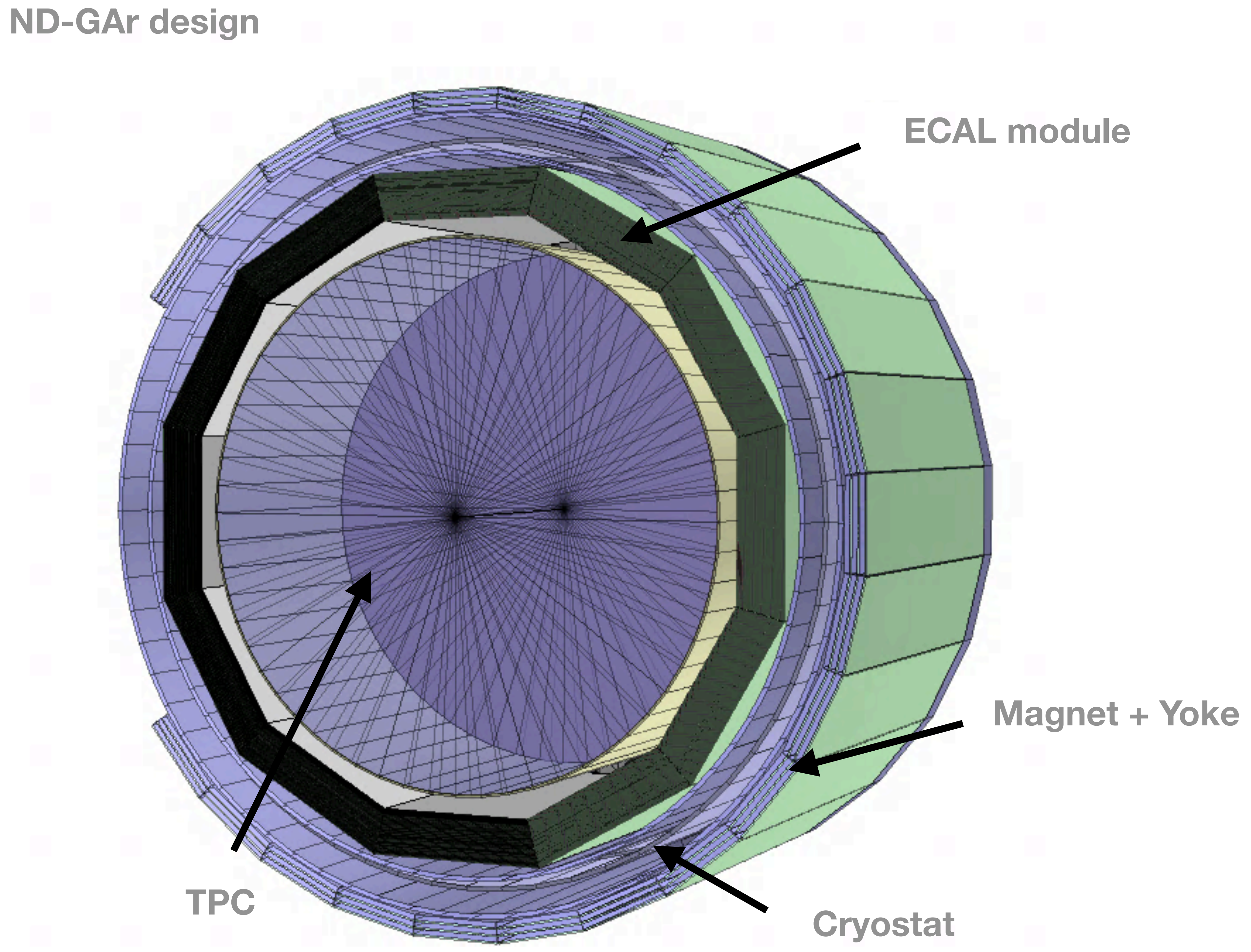


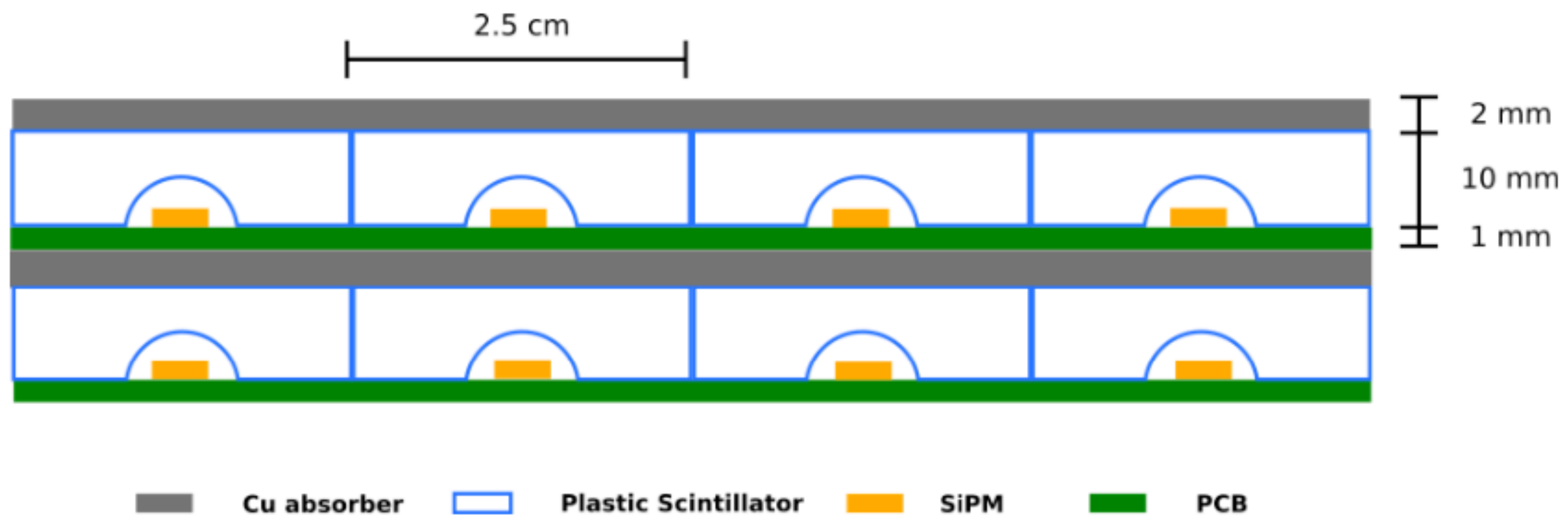
GOAT at Fermilab

The DUNE Near Detector: ND-GAr.

A high performance gas detector (ECAL)

- High performance **calorimeter** around the TPC
- Requirements
  - **Identify photons** from NC events ➠ position/angular resolution
  - Provide *complementary information* (PID, energy) ➠ energy resolution
  - **Precise timing** for t_0 (~ ns)
  - **Neutron** identification and energy measurement capability (ToF) ➠ sub-ns time resolution
- Key designs
  - **High granular** layers based on **CALICE** R&D (AHCAL SiPM-on-tile design)
    - 2 mm Copper / 5 mm plastic scintillator tiles of 2.5x2.5 cm^2
  - **Cross-striped** layers in the back based on Mu2e
    - 4 cm width spanning the full module width/length (~few m)
  - SiPM readout
  - Estimated number of channels: **~1 - 3M**





The DUNE Near Detector: ND-GAr.

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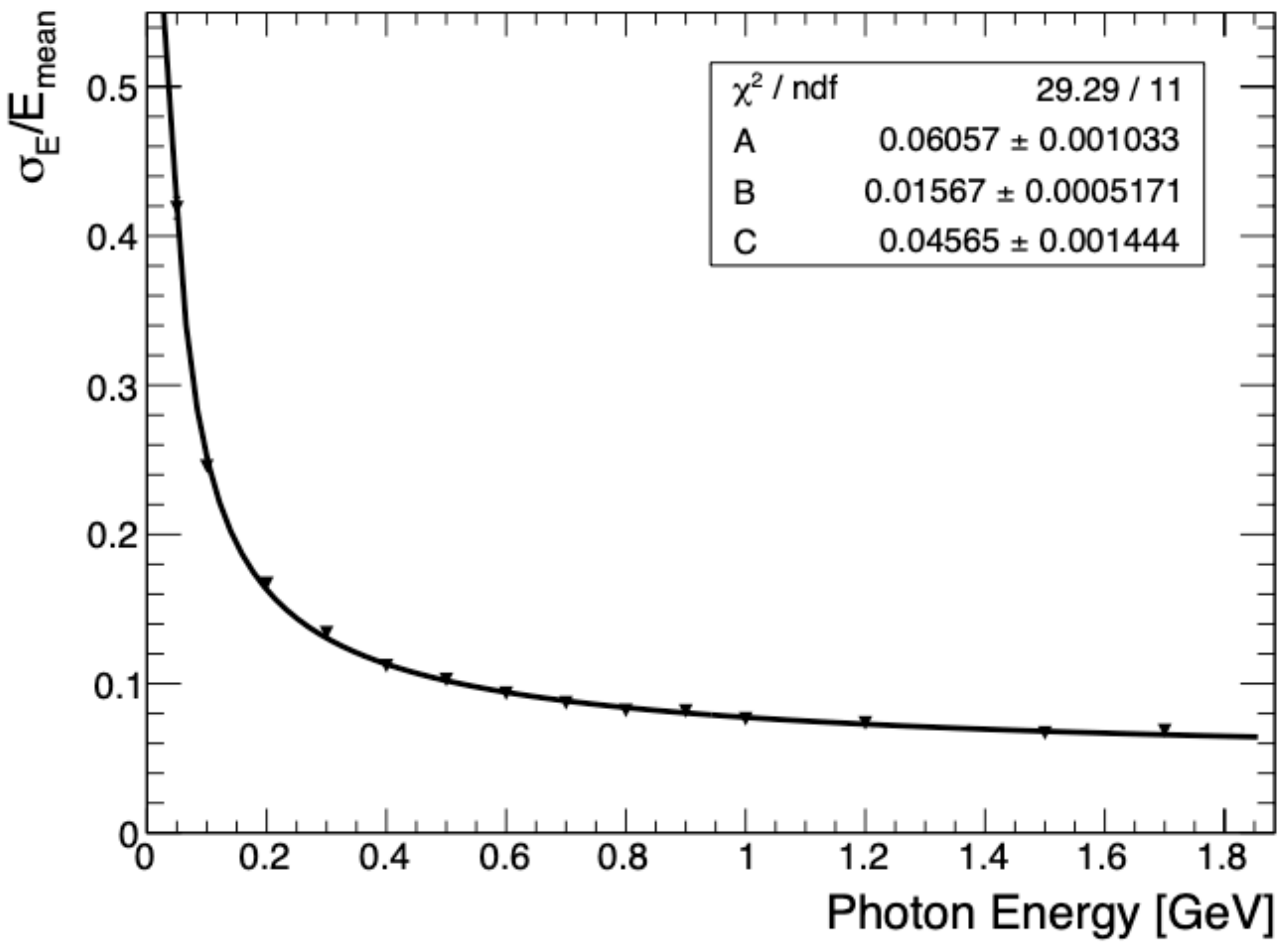
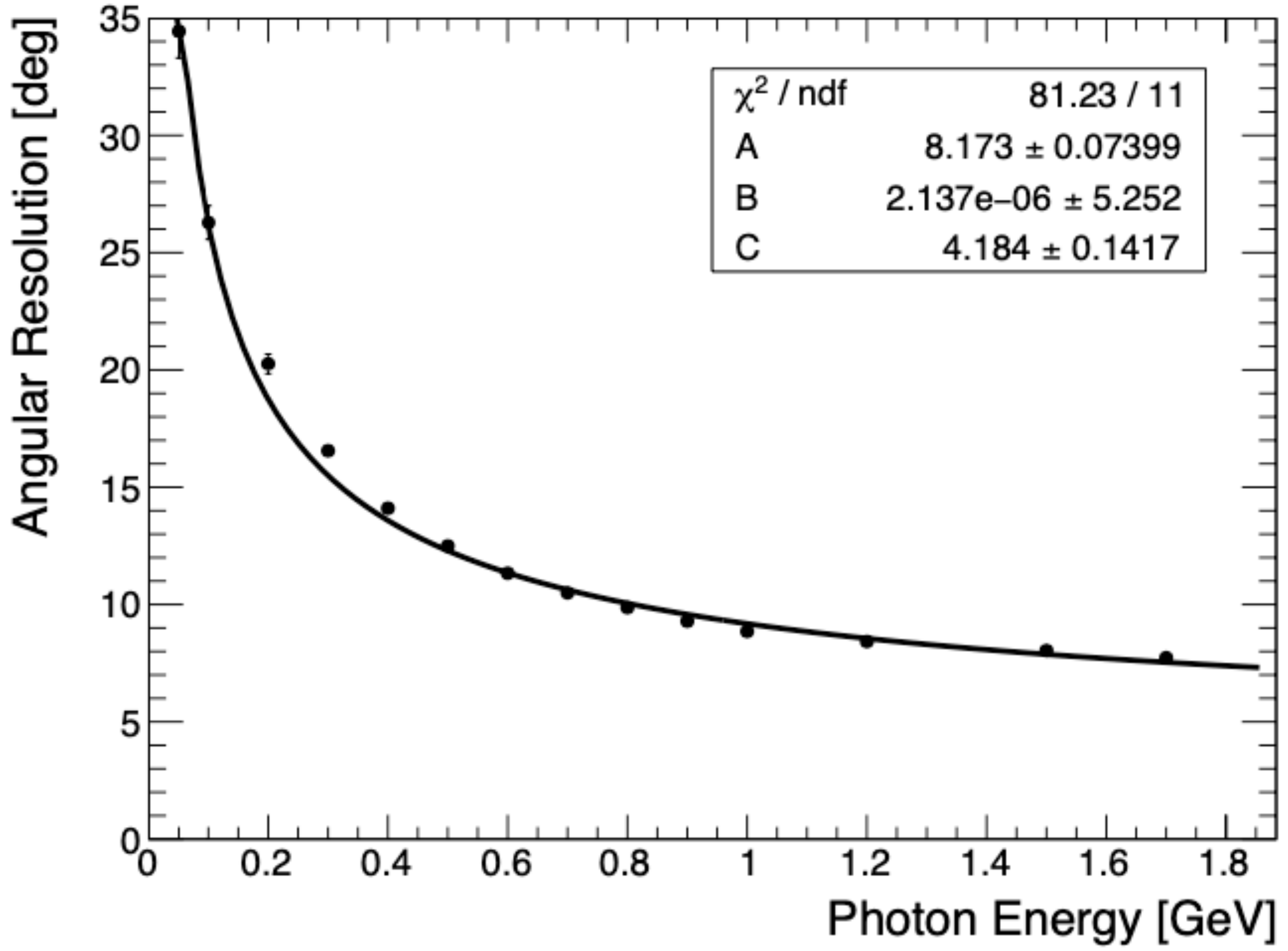
    - 4 cm width spanning the full module width/length (~few m)
  - SiPM readout
  - Estimated number of channels: **~1 - 3M**
- Estimated performance
  - Energy resolution ➠ 6%/ √E + 4%
  - Angular resolution ➠ 8°/√E + 4°

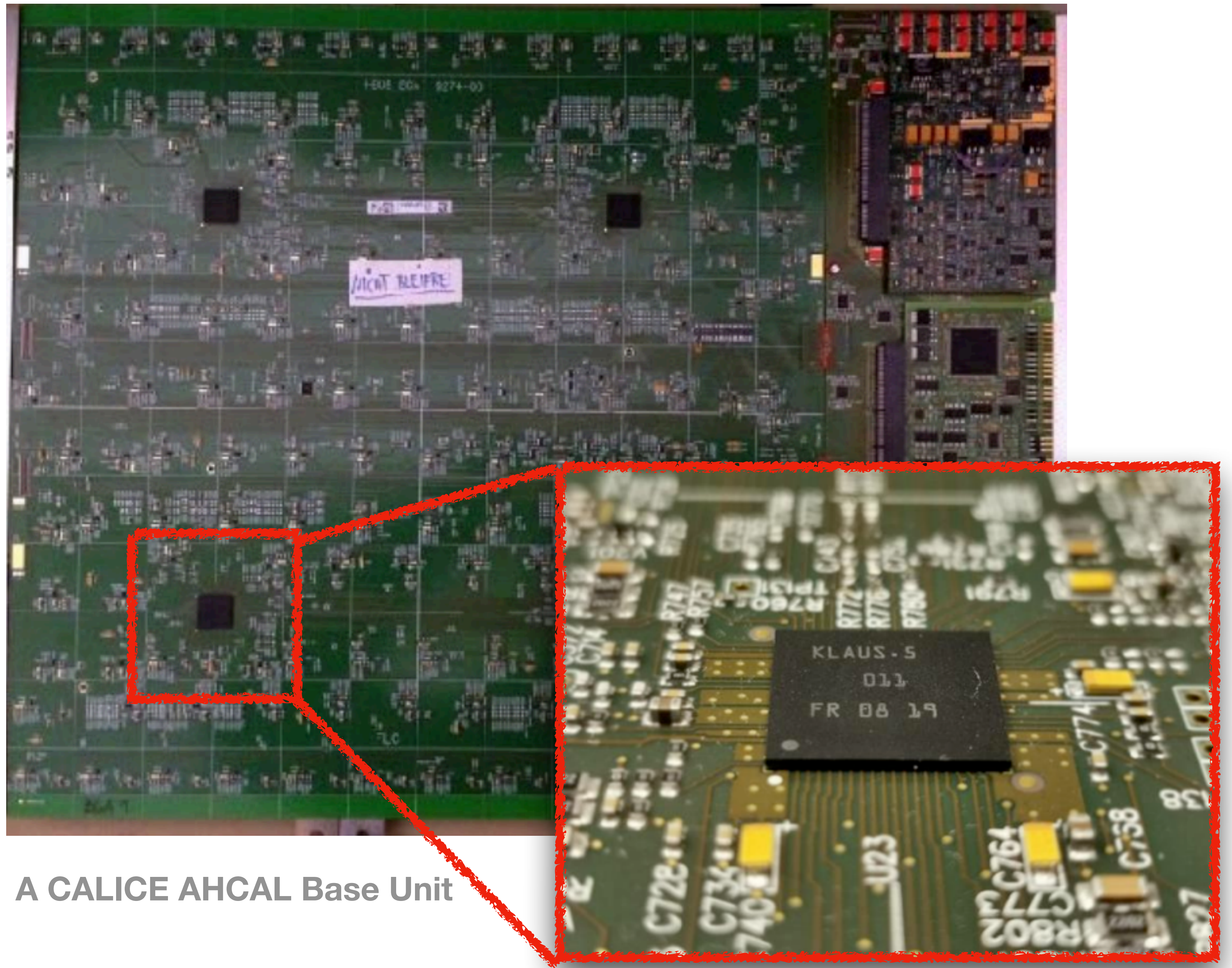




The DUNE Near Detector: ND-GAr.

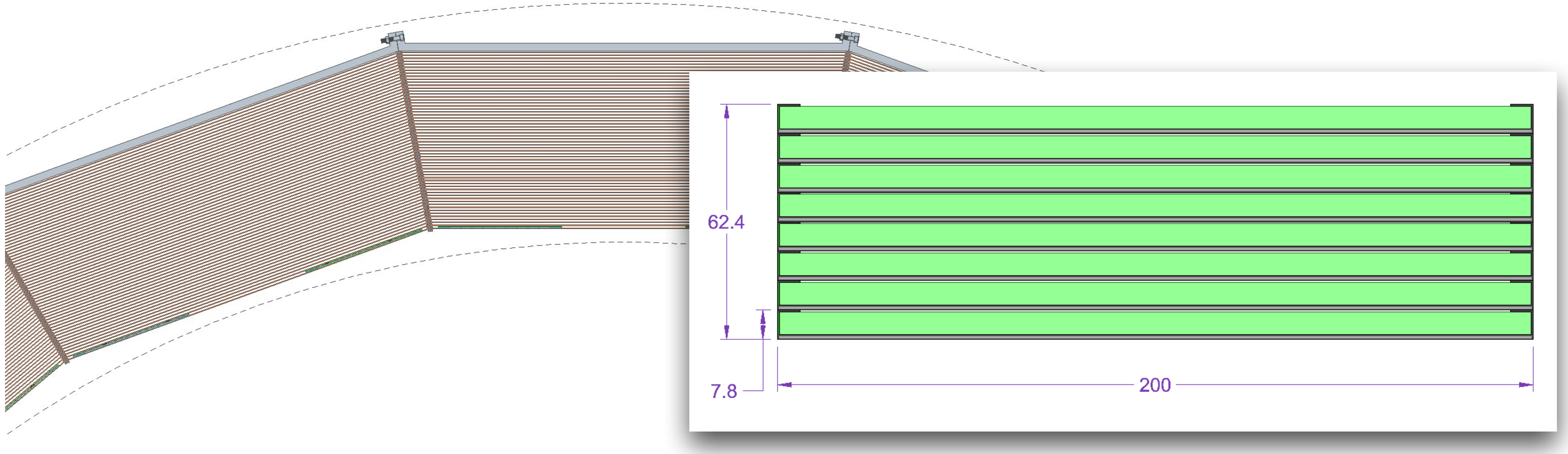
A high performance gas detector (ECAL)

- Readout electronics
  - HG layers: FE electronics **integrated** in the layer based on the CALICE AHCAL design
  - SiPM readout by ASIC ➠ likely **KlauS chip** (Heidelberg)
- Engineering and Integration
  - Ongoing studies to integrate the ECAL with the TPC and cryostat
  - Constant feedback to *optimise* and *identify* critical design issues
- Prototyping
  - Small *prototype* planned in the next years



A CALICE AHCAL Base Unit

KlauS-5 ASIC in BGA package

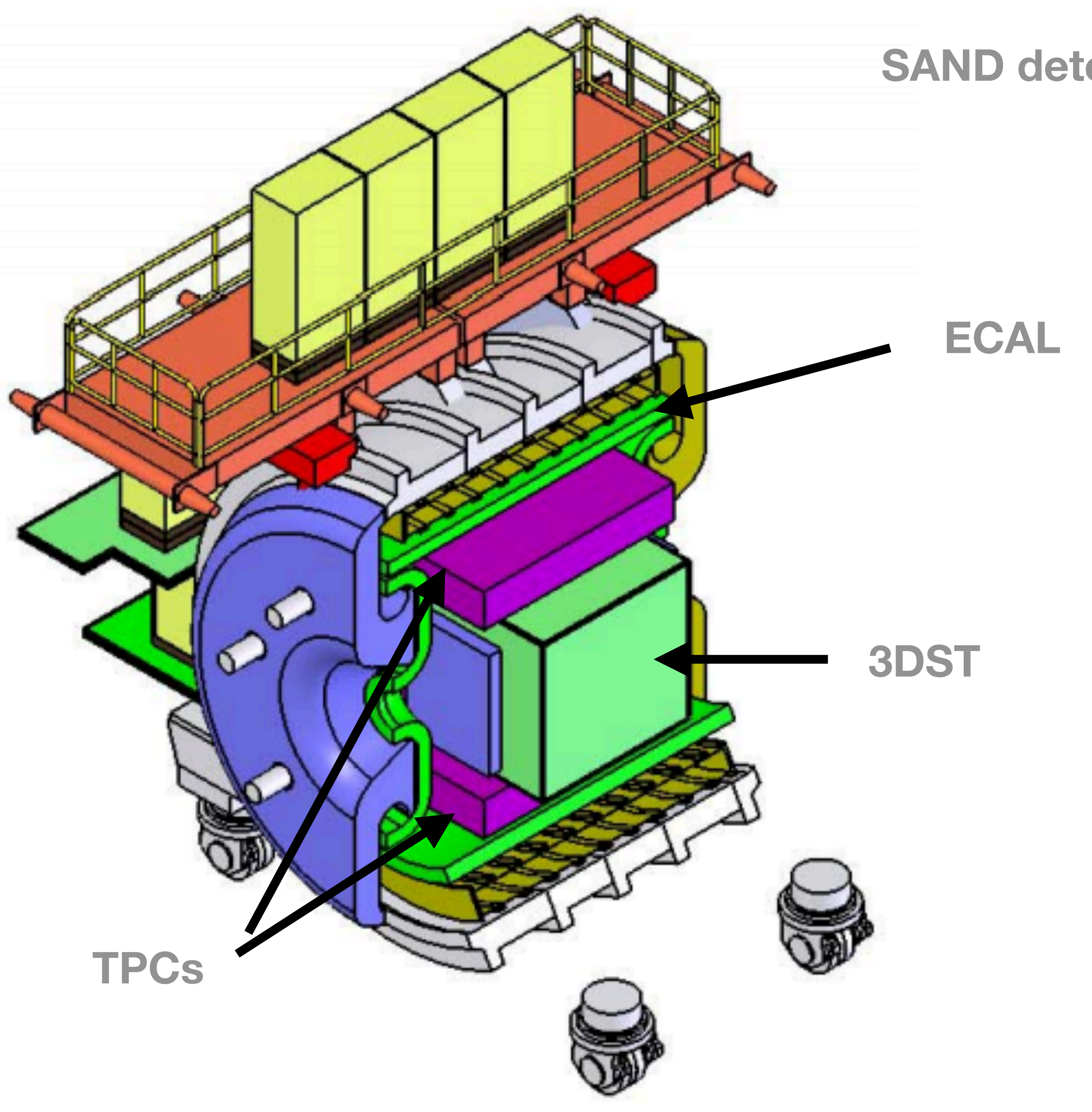


Module design for the ECAL

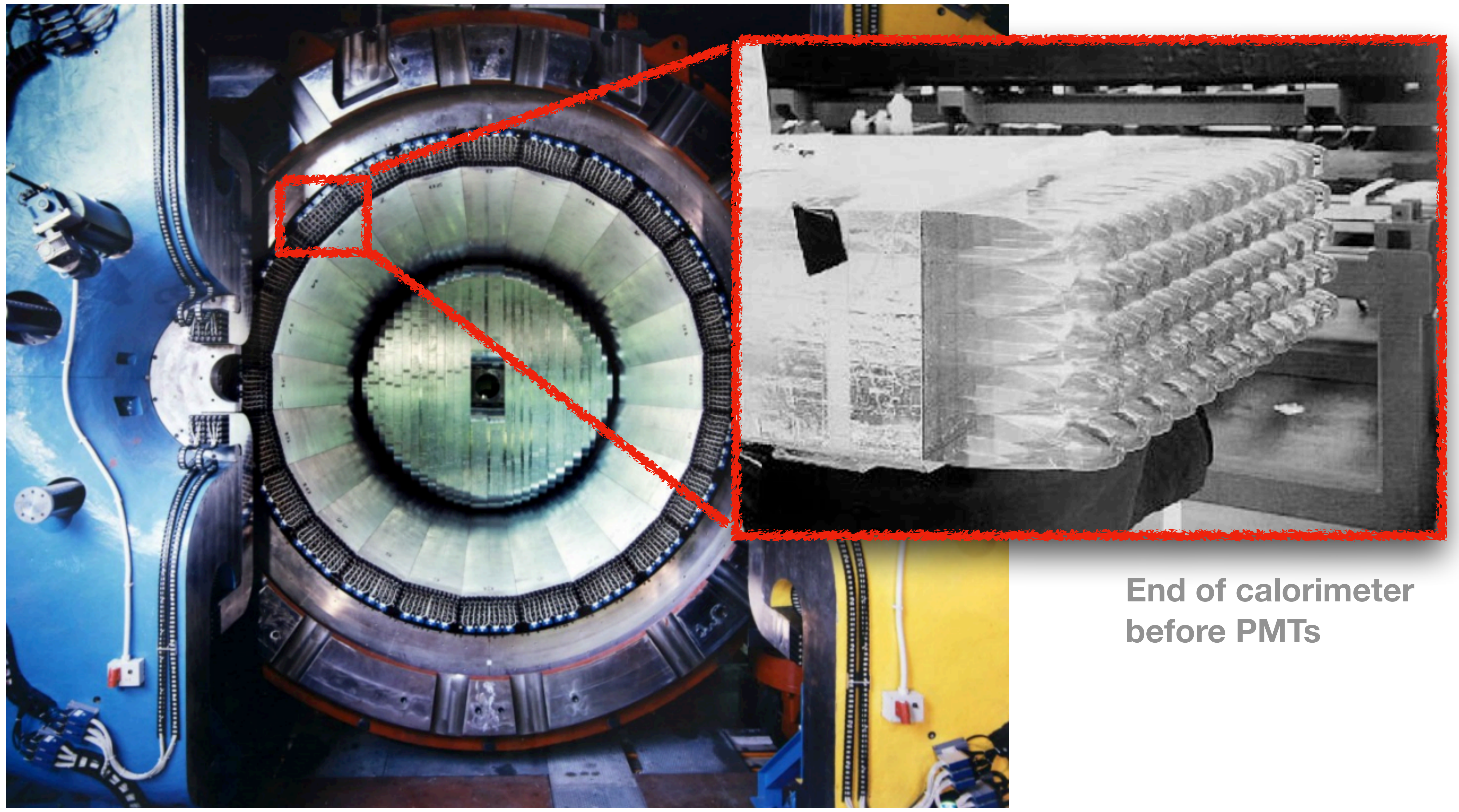
The DUNE Near Detector: SAND.

Beam monitoring detector with fully active tracker

- **SAND**: System for on Axis Neutrino Detection
  - Consists of a target tracker and calorimeter inside a magnet
- Requirements
  - **Beam monitoring** on few day basis
  - **Precision flux measurement** (neutrino beam flavor content)
- Several proposed designs
  - Fully active tracker: **3DST + TPCs**
  - **3DST** + Straw tube tracker (**STT**)
  - **STT-only**
- ECAL + Magnet
  - From the **KLOE** detector (Frascati)
  - Compact **Lead/Scintillating fibers** calorimeter readout by PMTs
    - Discussions ongoing on replacing the PMTs with SiPMs
    - Good energy resolution ~ **5%√E**
    - Very good timing resolution ~ **50 ps√E**
  - 0.6 T B-field



SAND detector design



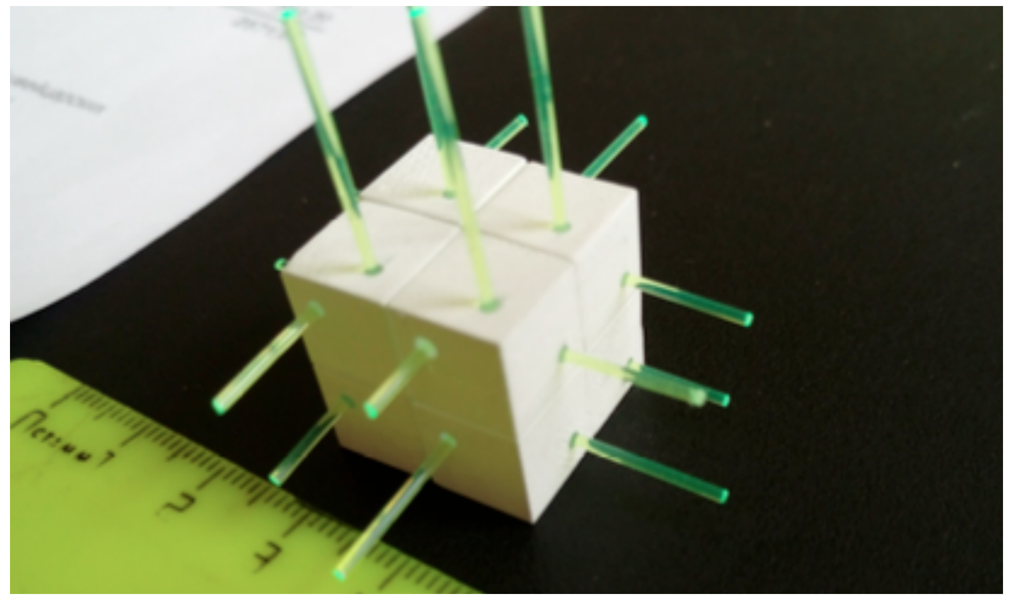
End of calorimeter before PMTs

KLOE detector

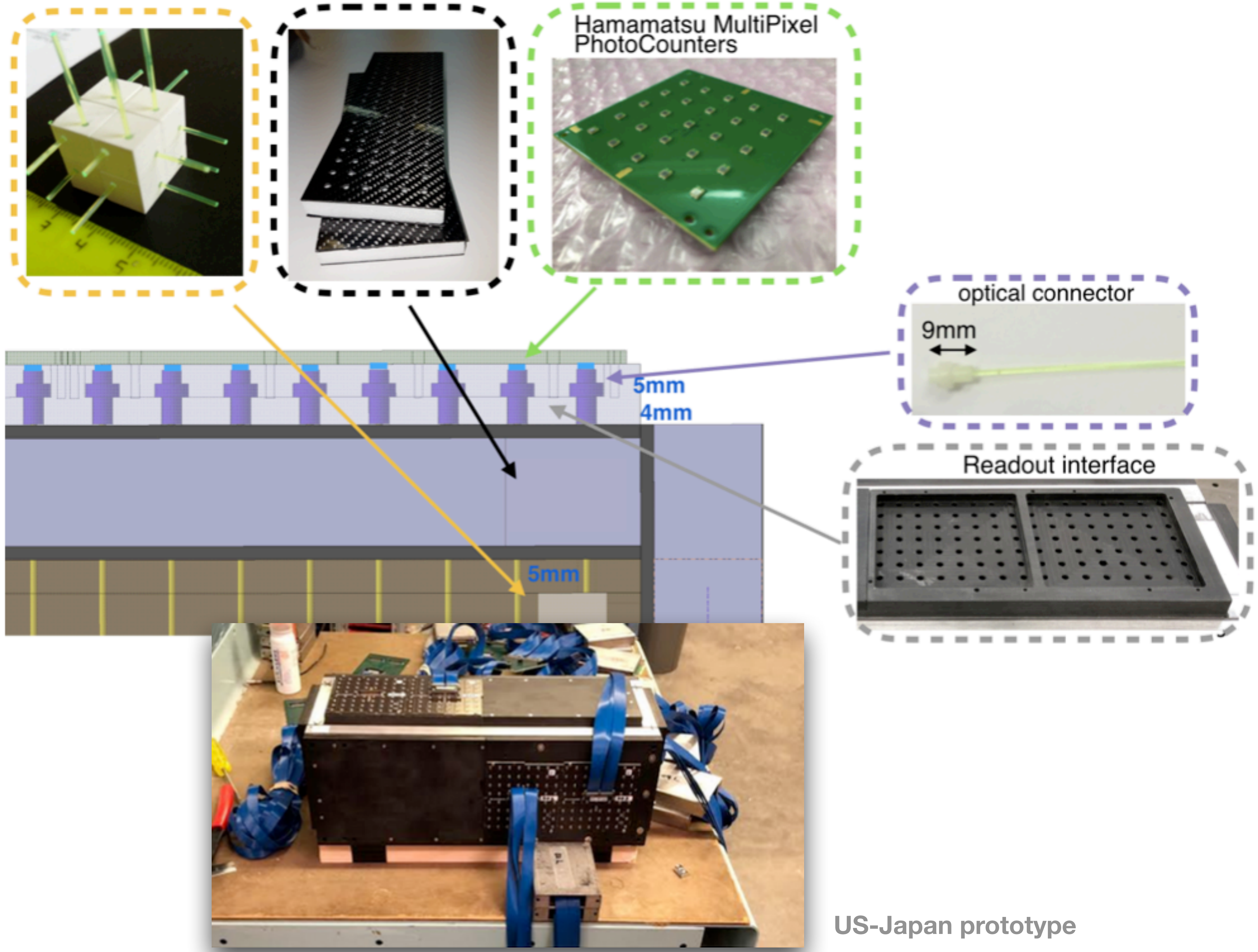
The DUNE Near Detector: SAND.

Beam monitoring detector with fully active tracker (3DST)

Assembly of 8 cubes



- Innovative tracking detector based on **SuperFGD** in T2K
- Active volume: 2.4 x 2.16 x 1.92 m^3
- 1.5x1.5x1.5 cm^3 plastic scintillator cubes
  - **Optically isolated** (chemical etching)
  - Readout by **3 orthogonal WLS fibers** (1 mm diameter)
- Provides full angular coverage and calorimetric measurement of the energy
- Number of cubes: ~ **3 M!**
- Readout
  - **MPPC** (S13360-1325PE) optically coupled to the fiber
  - Precise alignment with the readout interface board
- Front-End electronics
  - SuperFGD based on **CITIROC** ASIC
  - 3DST: Custom ASIC (possible **KlauS**) ➠ better time resolution, power consumption, production cost



US-Japan prototype

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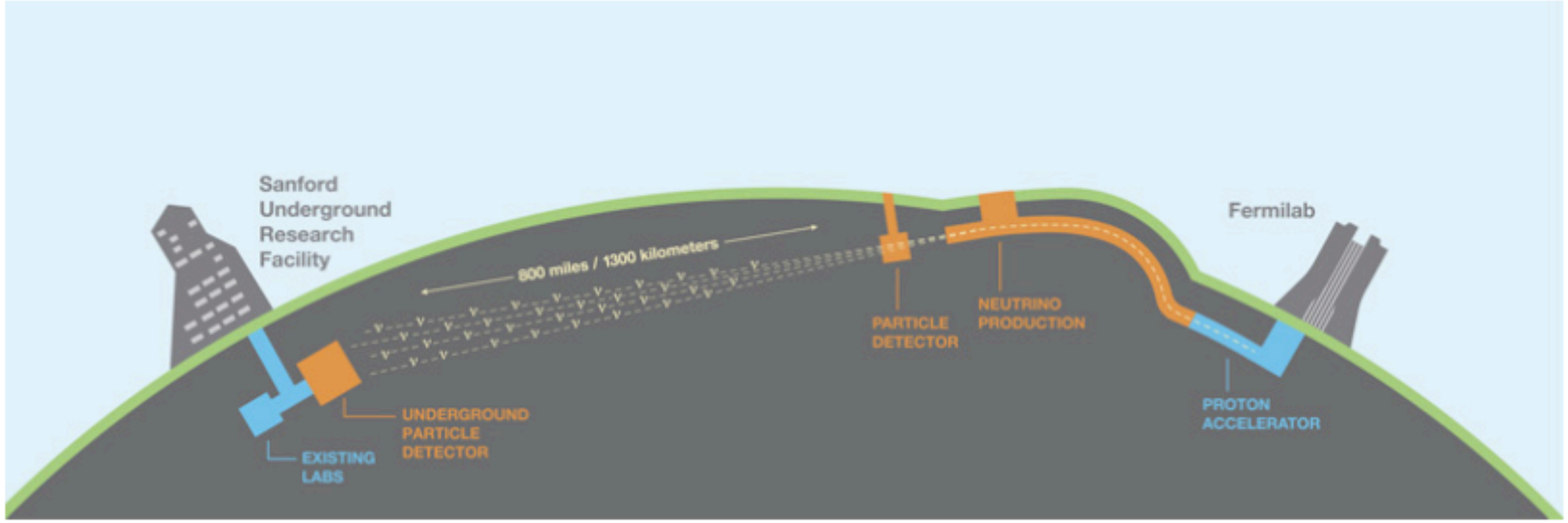

Summary.

An exciting future in particle physics

- The DUNE experiment is the next-generation long-baseline neutrino experiment
- It is pushing for:
  - new frontiers in neutrino physics
  - breaking technological limits throughout the FD and ND detectors
- The FD/ND are unique and using state of the art detector engineering
  - These unique designs will allow DUNE to reach its full potential
- This is an exciting time for young scientists to join this endeavour

Thank you for your attention.

References

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5. DUNE Near Detector Conceptual Design Report
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7. LArPix: Demonstration of low-power 3D pixelated charge readout for liquid argon time projection chambers (arxiv:1808.02969v3)
8. Vertical Drift Concept proposal: https://edms.cern.ch/document/2429382/1

Backup Slides.